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EDITED BY

K. HEADLAM-MORLEY

SECRETARY

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1939

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Offices—4, GROSVENOR GARDENS, LONDON, S.W.1.

Telegraphic Address—"IROSAMENTE, SOWEST, LONDON."

Telephone—SLOANE 0061.

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PREFACE.

THE present volume contains nine papers which had been prepared for presentation at the Autumn Meeting which, but for the outbreak of war, would have been held in Cardiff on September 12th to 15th, 1939. Subsequently a Statutory Autumn Meeting was held in London on November 23rd, 1939, but it was not possible to make provision for the verbal discussion of any papers on that occasion. However, contributions by correspondence on certain of the papers have been received and these have been included in the present volume.

The "Ninth Report on the Heterogeneity of Steel Ingots" (*Special Report No.* 27) was also prepared for the Autumn Meeting; a summary of the Report, some correspondence on it, and the replies by the authors of the Sections commented upon are likewise included in this volume.

Following the usual procedure, the volume is divided into two main Sections. Section I. contains the Minutes of Proceedings of the Statutory Meeting and the papers mentioned above. The Section concludes with biographical notes on deceased Members.

Section II. is devoted to a survey of the literature on the manufacture and properties of iron and steel, and kindred subjects, and consists of a collection of abstracts of articles from the Transactions and Proceedings of scientific societies and from the technical press. This Section also contains reviews of recent books and bibliographies of literature dealing with the manufacture and properties of iron and steel. The matter included in this Section has already appeared in the *Bulletin of the Iron and Steel Institute*, which is issued monthly.

In front of the title-page is inserted a list of the British Standardised Steel Samples issued jointly by the Iron and Steel Institute and the National Physical Laboratory, showing where and on what terms the samples are available. Proposal forms for Membership and Associateship and also for Joint Membership of this Institute and the Institute of Metals will likewise be found in the same place.

4, GROSVENOR GARDENS,
LONDON, S.W.1.
December, 1939.

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Abbreviations used in Text.

Å.	Ångström unit(s).
A.C.	air-cooled; alternating current.
A.H.	air-hardened.
amp.	ampère(s).
amp.hr.	ampère-hour(s).
atm.	atmosphere(s) (pressure).
Bé.	Baumé (scale).
b.h.p.	brake horse-power.
B.o.T.	Board of Trade.
B.Th.U.	British thermal unit(s).
C.	centigrade (scale).
cal.	calory; calories.
c.c.	cubic centimetre(s).
c.d.	current density.
c.g.s.	centimetre-gramme-second unit(s).
cm.	centimetre(s).
coeff.	coefficient.
const.	constant(s).
c.p.	candle-power.
cu.	cubic.
cwt.	hundredweight(s).
D.C.	direct current.
dia.	diameter(s).
dm.	decimetre(s).
e.m.f.	electromotive force.
F.	Fahrenheit (scale).
ft.	foot; feet.
ft.lb.	foot-pound(s).
g.	gramme(s).
gal.	gallon(s).
H.F.	high-frequency.
h.p.	horse-power.
h.p.hr.	horse-power-hour(s).
hr.	hour(s).
in.	inch; inches.
in.lb.	inch-pound(s).
K.	absolute temperature (Kelvin scale).
kg.	kilogramme(s).
kg.cal.	kilogramme-calory; -calories.
kg.m.	kilogramme-metre(s).
km.	kilometre(s).
kVA.	kilovolt-ampère(s).
kW.	kilowatt(s).
kWh.	kilowatt-hour(s).
lb.	pound(s).
L.F.	low-frequency.
m.	metre(s).
m.amp.	milliampère(s).
mV.	millivolt(s).
max.	maximum.
mg.	milligramme(s).
min.	minimum; minute(s).
ml.	millilitre(s).
mm.	millimetre(s).
m.m.f.	magnetomotive force.
N.	normal (solution).
N.T.P.	normal temperature and pressure.
O.H.	open-hearth; oil-hardened.
O.Q.	oil-quenched.
oz.	ounce(s).
p.d.	potential difference.
*p*H	hydrogen-ion concentration.
r.p.m.	revolutions per minute.
sec.	second(s).
sp. gr.	specific gravity.
sq.	square.
T.	tempered.
temp.	temperature.
V.	volt(s).
VA.	volt-ampère(s).
Wh.	watt-hour(s).
W.Q.	water-quenched.
yd.	yard(s).
°	degree(s).

SECTION I.

MINUTES OF PROCEEDINGS AND PAPERS OF THE IRON AND STEEL INSTITUTE.

AUTUMN MEETING

1939

Editorial assistance has been given by A. E. CHATTIN, B.Sc. (Hons. Met.), A.I.C., Assistant Secretary, in the preparation of this Section.

MINUTES OF PROCEEDINGS

OF THE STATUTORY

AUTUMN MEETING, LONDON, 1939.

THE AUTUMN MEETING OF THE IRON AND STEEL INSTITUTE, which, but for the war, would have been held in Cardiff on September 12th to 15th, was held on Thursday, November 23rd, 1939, at 3.30 P.M., at the offices of the Institute, 4 Grosvenor Gardens, London, S.W. 1. In the unavoidable absence of the President, Lord Dudley, Mr. JAMES HENDERSON (Vice-President) was in the Chair.

The CHAIRMAN (Mr. James Henderson), after expressing his appreciation of the honour done him, said that all the Members present would be sorry that the President of the Institute, Lord Dudley, was not with them that afternoon. Lord Dudley was the Regional Commissioner of Civil Defence for the Midland Region and was busily engaged on important work for the welfare of the country; he (the Chairman) suggested that the Secretary should be invited to write to Lord Dudley expressing the regret felt at his absence and wishing him good luck in the very important work which he was doing.

This was agreed to unanimously.

DEATH OF MR. CHARLES SCHWAB.

The CHAIRMAN (Mr. James Henderson) said his first duty was to record the deep regret felt by all the Members of the Institute at the death on September 18th last of Mr. Charles M. Schwab. Mr. Schwab was well known to them as one of the outstanding figures in the iron and steel industry of the world He was the Bessemer Gold Medallist of the Institute in 1928, and many would remember the occasion when he came to this country to receive the Medal and to invite the Institute to visit America. The sincere condolences of the Institute at this great loss had been conveyed to Mr. Schwab's family and to the Bethlehem Steel Corporation.

The Members stood in silence for a few moments as a token of respect.

THE ACTIVITIES OF THE INSTITUTE.

The CHAIRMAN (Mr. James Henderson) said the work of the Institute was continuing, and the offices at 4 Grosvenor Gardens remained open for the use of Members. Some change in the activities of the Institute, especially with regard to meetings and publications, had been necessitated by the war.

President.

Before referring to this, however, he wished to announce that Mr. John Craig, C.B.E. (Vice-President), had accepted the Council's invitation to become President of the Institute for two years from the Annual Meeting, 1940. Personally, he knew that Members would be as pleased as the Council to hear of Mr. Craig's decision, and would wish to thank him for doing the Institute the honour of accepting the invitation offered to him. (*Applause.*)

Membership.

The membership of the Institute had been well maintained; figures would be published in the spring as usual. There seemed to be no reason to expect a serious fall in numbers during the war, since it was hoped that new applicants connected with the industry in this country would outbalance any falling off in foreign membership. Some diminution in foreign membership was probably unavoidable, especially as currency restrictions made it difficult to transmit subscriptions. The Council had made reasonable provision for this contingency in framing their financial estimates. In accordance with Bye-law No. 36, the membership of German nationals lapsed on the outbreak of war. The autumn ballot list contained the names of well over a hundred candidates for Membership and Associate Membership.

Finance.

The Accounts of the Institute would, as usual, be presented at the Annual Meeting. On the present occasion he wished only to assure Members that the Council were keeping a very careful eye on all expenditure. The estimates which they had considered at their meeting earlier that afternoon were satisfactory.

As a result of the appeal which the President had issued in May, contributions of £13,033 8*s.* 0*d.* to the House Fund had been received, and annual subscriptions of £3,315 2*s.* 0*d.* had been promised from companies. Most of the leading companies in the industry had subscribed, and, on behalf of the Council, he wished to thank them for their generosity.

At the same time, the Council wished him to point out that there was still a very large number of companies from whom no contribution had been received. There was always a tendency for central organisations, and perhaps particularly research organisations, to be financed mainly by a limited number of companies, but

he ventured to suggest that the work of the Institute was of importance to all who were engaged in the manufacture of iron and steel, as well as to many who were re-rollers and manufacturers of steel products. He hoped that those companies also would subscribe, and he would ask Members of the Institute who were connected with companies to draw their attention to the President's appeal and to endeavour to ensure that it obtained the support of all members of the Federation and all companies connected with the industry.

Research.

The Joint Committees of the Institute and the British Iron and Steel Federation, which were part of the organisation of the Iron and Steel Industrial Research Council, were continuing their work. The Alloy Steels Research Committee, the Corrosion Committee, the Heterogeneity of Steel Ingots Committee and the Steel Castings Research Committee had all held meetings since the outbreak of war, and meetings of their twelve sub-committees had also been held.

Programmes for next year were now under consideration, and it was proposed that the various researches should be continued, and in some cases accelerated.

These Committees were part of the essential organisation for research. Moreover, they provided admirable means for dealing with any *ad hoc* problems affecting the industry, the solution of which might be required urgently owing to conditions arising during the war. He would take the opportunity of emphasising the necessity of maintaining in full all organisations dealing with research on behalf of the industry.

Meetings.

Owing to the outbreak of war, the Autumn Meeting, which was to have been held at Cardiff from September 12th to 15th, had had to be cancelled. The fact that Autumn Meetings had been cancelled in two successive years was a measure of the troubled times in which we lived. An excellent programme, with works visits in South Wales of outstanding interest, had been prepared, and 664 Members and Ladies had been expected to participate.

Had the meeting taken place, there would have been a more suitable opportunity of thanking Mr. Hollings, the Chairman, and the members of the Executive and Reception Committees. Mr. J. S. Hollings was the moving spirit of the meeting, and personally he would like to take the opportunity of thanking him on behalf of the Members, who would also wish to join him in thanking Mr. W. F. Cartwright, the Honorary Secretary, Mr. G. A. Young, the Honorary Treasurer, the managements of the works, and all who had assisted in making the arrangements. He hoped that they would ask the Institute to visit them again—*après la guerre.*

The Autumn Meeting next year was to have been held in France. He did not think that he was indiscreet in revealing that the Comité des Forges had proposed to invite the Institute; and, although a postponement had become necessary, no doubt the Members would like the Institute to express its appreciation to those who were once again allies—Monsieur E. Schneider (Past-President), Monsieur François de Wendel (President of the Comité des Forges), Professor A. Portevin (Bessemer Gold Medallist), and others who were interesting themselves in the meeting.

It was curious to note that a meeting had been arranged in Paris for September, 1914. That meeting eventually took place after the war, and it was hoped that early victory for the allied cause would make it possible for the Institute to have a meeting again in Paris soon.

Arrangements for meetings next year had not yet been completed. The Annual Meeting would be held as usual, probably in London, at a date to be arranged, and it was proposed to hold meetings in the main centres of production in order to give ample opportunity for technical discussion. It was hoped also to continue to hold joint meetings with local societies, as had been the practice of the Institute in the past. A number of local societies were continuing their normal arrangements, and, whatever might be possible in London, it was thought that it would be of material assistance to the industry if institutions in the provinces continued to hold meetings.

Publications.

The *Bulletin of Abstracts* was being published each month as usual.

Volume I. of the *Journal* for 1939 was published in the summer; the second volume would be issued in January. Arrangements for next year were not yet complete, but it was hoped to publish papers and the *Journal* as usual.

The issue of a *Monthly Journal* with a larger size of page would have to be postponed until after the war, but it was proposed to improve the Institute's service to Members by issuing papers in advance-copy form each month. Papers would be welcomed, and he would urge Members to submit papers on scientific and technical subjects connected with the industry.

Symposium on Blast-Furnace Practice.

The Symposium on Blast-Furnace Practice which was to have been held during the Annual Meeting next year had been postponed. It was hoped that Mr. Clements and his Committee would resume their work immediately the war was over.

The very favourable reception which had been accorded to the Symposium on Steelmaking, held two years ago, left no doubt as to the value of such meetings, at which practice all over the country

was discussed. Copies of the proceedings of the Symposium on Steelmaking were still available.

Joint Library.

The Joint Library of the Iron and Steel Institute and the Institute of Metals was continuing its usual activities, and was, he was glad to say, being widely used by Members of both Institutes. There had been some falling-off in the loan of books during the first weeks of the war, but the demand was now on the pre-war level. Licences had been granted to obtain foreign periodicals, including German technical journals. The Information Department was also operating as usual.

Prizes and Scholarships.

The Council would continue the award of prizes for suitable papers. For a number of years the Williams Prize, usually to the value of £100, had been awarded to the author of a paper of practical interest, and Captain Ablett had generously promised to renew his prize of £50 for a paper on steelworks engineering written by a junior engineer. The Council hoped that candidates would submit papers as usual; papers should be received before the end of January.

Carnegie Scholarships, generally of £100, would be awarded as usual.

Election of New Members.

The Secretary (Mr. K. Headlam-Morley) announced that the following ninety-seven Members and fifteen Associates had been elected:

Members.

Abbott, William Robert	Kettering.
Adams, Arthur Basil	Newport, Mon.
Alexandre, Henri Léon	Ougrée, Belgium.
Alker, Thomas Edwin	Rhiwbina, Glam.
Allen, William Davies	Rotherham.
Berg, Torsten	London.
Bird, William Herbert Richard, M.A., B.Sc.	Ebbw Vale, Mon.
Bottoms, James Robert	Ebbw Vale, Mon.
Bracey, John Arthur	Swansea.
Brooke, Norman Richard Rowley	Cardiff.
Brown, Edgar	St. Mellons, near Cardiff.
Brown, Edgar Frankish	Saltburn-by-the-Sea.
Brown, William Robson, A.M.I.M.E.	London.
Brûce-Gardner, Douglas, B.A.	Manchester.
Colley, Howell Cecil	Rogerstone, Mon.
Crisp, Nathaniel William, A.M.Inst.C.E.	London.
Croxford, Cyril	Cardiff.

DANIELS, ARTHUR WYLDE, A.M.I.Mech.E.	Birmingham.
DAVEY, HERBERT JOHN	London.
DAVIES, EVAN ARNOLD	Swansea.
DAVIS, LEONARD SHAW	London.
DEACON, GORDON EDWARD	Swansea.
DONNELLY, VICTOR JOHN	London.
EVANS, SYDNEY WILLIAM, B.Sc.	Cardiff.
FIELD, ALEXANDER LITTLEJOHN	Baltimore, Md., U.S.A.
FLETCHER, PEEL	London.
FLETCHER, WILLIAM EDWIN RONALD	Newport, Mon.
GEARY, EDWARD POWELL	Darlington.
GIPS, WALTHER	Luanshya, N. Rhodesia.
GOODCHILD, EDMUND ARTHUR	Chelmsford, Essex.
GRAEFF, SIDNEY ERNEST	Ebbw Vale, Mon.
GREEN, ARTHUR CADDICK	Newport, Mon.
GREEN, SIMON, B.A. (Cantab.)	Wakefield.
GRUNTHAL, PAUL	London.
GRUVER, ROBERT S., B.A.	Abergavenny, Mon.
HARRIS, ARTHUR CLEMENT, Assoc. Met.	Napuria, Bengal, India.
HARRISON, MAYNARD COLCHESTER	Port Talbot, Glam.
HELMER, N. E. GOVERT	Bofors, Sweden.
HERBERT, IVOR	Beaufort, Mon.
HICKS, GEORGE	Dowlais, Glam.
ISIDA, SIRO, D.Sc.	Tokyo, Japan.
JAMES, JOHN FREDERICK ROBERT	Chester.
JENKINS, WILLIAM AUGUSTUS	Newport, Mon.
JENKINSON, EUGEN ALEXANDER, B.Sc. (Eng.)	Teddington, Middlesex.
JOHNSON, EVA DELL, M.S.	Bridgeville, Pa., U.S.A.
JONES, KARL MEREDITH	Neath, Glam.
KHAN, MALIK AKBAR ALI	Hyderabad, Deccan, India.
KILBY, ALAN	Scunthorpe, Lincolnshire.
KROTOFF, *Dr.* IVAN VASILIEWITCH	Moscow, U.S.S.R.
LAW, LIONEL WILLIAM, M.A., A.M.I.E.E.	Wolverhampton.
LEWINGTON, GORDON RENDELL	London.
LINLEY, DOUGLAS	Rotherham.
LORMER, ROBERT JOHN	Melbourne, Australia.
LOUBSER, MATTHYS MICHIEL, B.A. (Hons.), Dipl.-Ing., M.Inst.Loc.E.	Pretoria, S. Africa.
LYNAM, THOMAS RICKMAN	Oughtibridge, near Sheffield.
MCBEAN, AENEAS, B.Sc. (Eng.)	District Manbhum, India.
MALCOLM, ROBERT, B.Sc., A.I.C.	Stirling.
MAUGHAN, RALPH ROBERT COUTTS	Swansea.
MEIER, HERBERT	Ebbw Vale, Mon.
MENZIES, GEORGE MACBETH	Bathgate.
MOCHEL, NORMAN LUTHUR	Ridley Park, Pa., U.S.A.
MOREN-BROWN, HUBERT, A.M.I.Mech.E.	Hockley Heath, Warwickshire.
MORGAN, JOHN V.	Irlam, Manchester.
MURRAY, WILLIAM	St. Mellons, near Cardiff.

MYERS, JOHN, F.I.C.	Newport, Mon.
NICKSON, JOHN WILLIAM	Connah's Quay, near Chester.
OVESEN, HENRIK	Chester.
PARKER, ALBERT ERNEST	Cardiff.
PARR, FRANK EDMESTON	London.
PARRACK, HARRY OWEN, B.Sc. (Lond.)	London.
PARRY, WILLIAM HENRY	Lydney, Gloucestershire.
PATON, JOHN ROY	Cardiff.
PEARSON, LIONEL REX, A.M.I.Mech.E.	Abergavenny, Mon.
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PERRIN, RENÉ MARIE VICTOR	Paris, France.
PHIPPS, GEORGE ALFRED	Cardiff.
PODE, EDWARD JULIAN	Port Talbot, Glam.
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REMSEN, JAMES K.	Darlington.
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TAYLOR, CYRIL GEORGE ALLEN	Llanelly, Carmarthenshire.
THOMAS, WILLIAM ROSSER	Newport, Mon.
TRIANO, *Marques de*	Bilbao, Spain.
TROXEL, FRANK ALBERT	Ebbw Vale, Mon.
TULIP, EDWARD JAMES, M.Inst.P.I.	Richmond, Surrey.
WHILE, HAROLD ARTHUR ARMSTRONG, M.A.	Wolverhampton.
WILLIAMS, EZEKIEL	Llanelly, Carmarthenshire.
WRIGHTSON, PETER	Thornaby-on-Tees.
YOUNG, DAVID JOHN	Port Talbot, Glam.

ASSOCIATES.

BEARDMAN, EDWARD LAWRENCE	Cleveland, Ohio, U.S.A.
BORTHWICK, T. G.	Glasgow.
CLAYTON, CHARLES LEE	Pittsburgh, Cal., U.S.A.
CURTIS, JOHN GORDON	Rotherham.
FORNANDER, SVEN G. E.	Uddeholm, Sweden.
GAY, WILLIAM ALLAH	Abadan, Iran.
GÖTHBERG, KARL GUSTAF	Stockholm, Sweden.
JACKSON, ROLAND, M.Sc., Ph.D.	Accrington.
McCAFFERTY, SAMUEL	Glasgow.
MORRAL, FACUNDO ROLF	Kokomo, Ind., U.S.A.
PARRY, ROBERT WILLIAM PRITCHARD	Lydney, Gloucestershire.
PRICHARD, MICHAEL ANDREW	Barry, Glam.

SCOTT, ALEXANDER . . .	Glasgow.
THOMSON, JOHN	Galston.
WATERFIELD, ANTONY HENRY .	London

AWARD OF ANDREW CARNEGIE RESEARCH SCHOLARSHIPS FOR 1940.

The SECRETARY (Mr. K. Headlam-Morley) announced that the following Andrew Carnegie Research Scholarships had been awarded for 1940 :

F. L. GILLEMOT (Technological Institute, Budapest, Hungary) : £100 in aid of a research on the influence of the base material and manufacturing procedure on the fatigue of wire ropes.

T. P. HOAR (Metallurgical Laboratories, Cambridge University) : £100 for a study of the conditions leading to intensive corrosion.

A. LATIN (Department of Metallurgy, Manchester University) : £100 for a critical review of existing knowledge concerning the structure of ingots (to be carried out on behalf of the Committee on the Heterogeneity of Steel Ingots, a Joint Committee of the Institute and the British Iron and Steel Federation).

G. PARKER (the University, Leeds) : £100 in aid of a research on the oxidation and scaling of steel (to be carried out on behalf of the Alloy Steels Research Committee of the Institute and the British Iron and Steel Federation—second grant).

PAPERS PREPARED FOR THE MEETING IN CARDIFF.

The SECRETARY stated that the Ninth Report on the Heterogeneity of Steel Ingots and numerous other papers had been prepared with a view to discussion at the Autumn Meeting in Cardiff. These had been set in type and advance copies had been circulated in the usual way before the outbreak of war. There was now no opportunity to discuss them verbally at the present Meeting, but they would be printed as usual (the Ninth Report on the Heterogeneity of Steel Ingots had been published as *Special Report No.* 27, and the papers and the correspondence on them and on the Ingot Report would be found in the present volume of the *Journal*).

CHAIRMAN'S CLOSING REMARKS.

The CHAIRMAN (Mr. James Henderson), in closing the Meeting, said it must have established a record for brevity. He thanked the Members for their attendance, and said it was desired to emphasise that the activities of the Institute would be carried on to the fullest possible extent. It must be appreciated, he added, that, while dates were being put down for meetings next year, these must be, to some extent at any rate, of a provisional character, and circumstances might arise which would make it difficult for the dates to be adhered to. With that proviso, however, the Institute would be glad if the fullest publicity could be given to its intention to carry on its activities, which were regarded as no less important to-day than in pre-war times, and if anything as more important. (*Applause.*)

Complete List of Papers Prepared for the Autumn Meeting in Cardiff, 1939, including a Special Report.

"NINTH REPORT OF THE HETEROGENEITY OF STEEL INGOTS." Being a Report by a Joint Committee of the Iron and Steel Institute and the British Iron and Steel Federation to the Iron and Steel Industrial Research Council (*Special Report No.* 27).

A. J. BRADLEY and H. J. GOLDSCHMIDT: "An X-Ray Investigation of the Iron-Rich Nickel-Iron Alloys."

R. GENDERS and R. HARRISON: "Niobium-Iron Alloys."

ROOSEVELT GRIFFITHS: "The Causes of 'Roll-Marks' on Tinplate."

T. P. HOAR, T. N. MORRIS and W. B. ADAM: "The Influence of the Steel-Base Composition on the Rate of Formation of Hydrogen-Swells in Canned-Fruit Tinplate Containers.—Part I."

H. JOLIVET: "Transformation of Austenite on Cooling; Morphology and Genesis of the Aggregates Formed."

B. JONES and J. D. D. MORGAN: "Antimony in Mild Steel."

Count Bo KALLING and IVAR RENNERFELT: "Decarburisation of Granulated Pig Iron: The 'R.K.' Process."

A. L. NORBURY: "The Effect of Casting Temperature on the Primary Microstructure of Cast Irons. Theories of Dendrite Formation and of the Solidification of Iron-Carbon Alloys."

H. W. SWIFT: "Tensional Effects of Torsional Overstrain in Mild Steel."

AN X-RAY INVESTIGATION OF THE IRON-RICH NICKEL-IRON ALLOYS.*

By A. J. BRADLEY, M.A., D.Sc., F.R.S. (Cambridge), and H. J. GOLDSCHMIDT, M.Sc. (Research Department, William Jessop & Sons, Ltd., Sheffield).

Summary.

X-ray powder photographs of iron-nickel alloys have been taken after long times of heat treatment. They give unexpected results, which cannot be explained on the basis of current views. In spite of the fact that there are only two types of structure (body-centred cubic and face-centred cubic), the system is quite complicated. Reactions take place at two definite temperatures, 580° and 350° C. Below 580° C. there is a sudden broadening of the two-phase gap, which is quite narrow above this temperature. From 580° down to 350° C. $\alpha + \gamma$ two-phase structures are formed at all compositions between about 6–8% nickel (α) and 23–26 atomic-% nickel (γ). At about 350° C. the α and γ phases react to form α_1 with the approximate composition Fe_3Ni, which is a low-temperature body-centred cubic phase. It is impossible to get direct evidence for the two-phase region $\alpha + \alpha_1$, because the lattice spacings are almost identical. The $\alpha_1 + \gamma$ region stretches from about 25 to 40 atomic-% nickel at 325° C. Invar, the composition of which places it in this region, must be regarded as a supersaturated γ solid solution which may under certain conditions of heat treatment precipitate Fe_3Ni.

Introduction.

A comprehensive survey of the numerous papers dealing with the nickel-iron equilibrium diagram has recently been given by Desch.[1] In spite of investigations during many years this system is still very imperfectly understood. The results of thermal, microscopical and magnetic work cannot yet be explained in accordance with the phase rule. Two entirely different types of diagram have been suggested, one postulating the existence of a eutectoid, the other requiring only two single-phase fields.

(*a*) *The Eutectoid Hypothesis.*—In order to account for the microstructure of meteoritic alloys of iron and nickel, Osmond and Cartaud [2] published a diagram with a eutectoid towards the iron-rich end of the system. This theory was supported by the careful microscopical and thermal studies of Hanson and Hanson,[3] who arrived at a similar type of diagram. The main feature relevant to the present work is the existence of a eutectoid horizontal at 345° C. stretching from 8% to about 32% nickel, the eutectoid composition being 25%. The evidence in support of this hypothesis

* Communication from the National Physical Laboratory, received March 3, 1939.

is largely microscopical, the thermal results being for the most part at variance with the proposed diagram.

(*b*) *The Two-Phase Hypothesis.*—If the results of microscopical work be ignored, there is no basis for the eutectoid theory. It is a simple matter to construct a rough diagram from thermal and magnetic data below 1000° C. which shows only three phase-fields : α, $\alpha + \gamma$ and γ. The exact placing of the phase-boundaries is, however, greatly influenced by the experimental methods in use. This is due to the depression of the transformation during cooling and its elevation during heating. There are for this reason two distinct ranges in which the transformation is believed to occur. It is clear that this is not to be regarded as an equilibrium diagram. It only purports to show what happens if an alloy is heated up or cooled down, without necessarily being in equilibrium at any stage.

X-ray investigations have discredited the eutectoid hypothesis, by showing that the so-called γ–γ' transformation in the nickel-rich alloys is merely the magnetic change point, and cannot have anything to do with a eutectoid. The second type of diagram seemed to fit the facts better, since there are only two types of atomic arrangement—body-centred cubic (α) and face-centred cubic (γ). Attempts to delineate the phase boundaries on this basis have proved unsatisfactory. The authors have therefore carried out a comprehensive series of investigations in the hope of providing an alternative explanation of the X-ray results. Before describing these experiments, it is necessary to refer to the difficulties which have to be faced in dealing with this system.

Sluggishness.

The main difficulty in dealing with iron-nickel alloys is that transformations take place below 600° C., where the alloys have become very sluggish. The first object of the present research was to find how the cooling rate influenced the structure and so to arrive at some idea of the times required for the attainment of equilibrium at any given temperature. It was found that cooling rates as slow as 10° C. per hr. did not permit equilibrium conditions to be followed below 600° C. A more effective treatment was to lump-anneal for 9 days at 570° C., after which a comparatively short heating of the powders at the same temperature gave consistent results. At lower temperatures much longer times of annealing were required before the powders approached equilibrium conditions. Table I. gives a rough idea of the relation found between time and temperature.

The numbers shown in Table I. are intended more for the purpose of clarifying our ideas than for the object of giving precise quantitative values, for which the data are still lacking. These figures in any case are only valid for powders which have been treated in a certain manner. Solid specimens, and above all single crystals,

would be expected to behave in quite a different fashion. In general, one would expect far longer times to be necessary.

TABLE I.—*Minimum Times * to Approach Equilibrium in Powdered Iron-Nickel Alloys.*

Temperatures. ° C.	Times.
600	1 day
550	3 days
500	1 week
450	3 weeks
400	2 months
350	6 months
300	1 year

* After previous heat treatments at higher temperatures.

Rapid Changes during Cooling.

It is remarkable that alloys which are so slow in reaching equilibrium should under other conditions be capable of undergoing rapid transformations. For example, the time taken for the attainment of equilibrium at 350° C. is not less than 6 months, and yet cooling curves clearly indicate the occurrence of instantaneous transformations at this temperature. Magnetic measurements show similar results. It seems probable that there are two quite distinct processes, one of slow diffusion, the other of rapid gliding. Only the former is directly connected with the equilibrium diagram, and it is this slow diffusion process which is the subject of the present investigation.

The rapid gliding process, though of great importance, has in most cases little to do with the equilibrium diagram. Dehlinger [4] has, however, shown that experiments on the rate of transformation of an alloy with 29% of nickel can be used to fix the phase boundaries for this composition. Unfortunately the effects of this process cannot be excluded from experiments made above 600° C. For this reason the X-ray results give direct evidence of the thermal equilibrium diagram only below 600° C., which is precisely where difficulties due to sluggishness begin to be important. In spite of this dual handicap, it has been found possible to interpret almost all the X-ray photographs and to construct a new phase diagram on the basis of the information so obtained.

The Present Experiments.

Alloys were made up at intervals of about 3% of nickel between 0 and 35 atomic-% of nickel, by melting together pure iron and pure nickel (Hilger's 8038 and 7636), the overall purity being 99·97%. A high-frequency induction furnace was used and the alloys were

lump-annealed and powder-annealed under conditions to be described. All heat treatments were carried out *in vacuo*.

X-ray powder photographs were taken at room temperature after subjecting the filings to a variety of different heat treatments. Since the authors had no idea of the nature of the results which were to be obtained the experiments were at first only directed towards finding suitable conditions for heat treatment. It was only near the end of the work that it began to appear probable that the results could be explained by a true equilibrium diagram. For example, no less than sixteen different photographs were taken of one alloy in order to find how it would behave under different conditions.

In all, seven main series of experiments were made. The first two have already been briefly referred to in a previous paper.[5] The list of experiments is as follows (*see also* Tables III. to VIII. in an Appendix):

(1) A comparison of the results of slow and rapid cooling.
(2) A test of the effect of liquid air on slowly cooled alloys.
(3) A comparison of the results of lump-annealing above and below 600° C.
(4) A comparison of the effects of powder-quenching above and below 600° C.
(5) A test of the effect of prolonged heating at 450° C.
(6) A test of the effects of prolonged heating at 350° and 325° C.
(7) A comparison of the behaviour of a given alloy (with 16% of nickel) under different conditions.

The Interpretation of the Powder Photographs.

In each of the above experiments a series of X-ray powder photographs was taken. Only face-centred cubic (γ) and body-centres cubic (α) structures were found. The alloys containing the least nickel were always body-centred cubic; those with most nickel were face-centred cubic; but in the intermediate range (between 7 and 25% of nickel) the structures were sometimes face-centred, sometimes body-centred and sometimes mixtures, depending on the details of the heat treatment. It was quite out of the question to relate the results directly to a phase diagram, since it was obvious that in some cases equilibrium had never been attained during the heat treatment, whereas in other cases there were transformations while the alloy was cooling down to room temperature.

To distinguish alloys which have retained their original state from those which have been transformed during quenching, attention must be paid to the sharpness of the X-ray reflections. Normally one tries to devise a technique which will make the lines as sharp as possible. This is done by lump-annealing at as high a temperature as possible to remove coring and segregation, followed by heat treatment of the powder to remove the effects of cold-working due to filing. The X-ray powder photograph should have sharp lines

if it is taken at the temperature of powder-annealing or after cooling to room temperature, provided that no further transformation occurs during the time of cooling. In experiments 2 to 7 coring and segregation were completely eliminated by lump-annealing at 1300° C. Any lack of sharpness in the lines was, therefore, due to other causes. All such causes may be grouped under one heading —rapid transformations in the solid state produced by gliding processes.

In these experiments, the γ lines were always sharp or at least fairly sharp, because this phase was formed at a high temperature where diffusion was rapid. The body-centred cubic lines were sharp when the alloy was allowed time to get into equilibrium after the γ–α transformation; they were diffuse when the body-centred cubic structure was formed by a sudden transformation at a lower temperature, and was not allowed time to settle down again before cooling to room temperature. For example, alloys with only a few per cent. of nickel change to the α form above 800° C. On quenching from the γ state these alloys instantaneously change over to the α form, and the X-ray powder photograph taken at room temperature shows fairly sharp lines of the body-centred cubic pattern. Here the great mobility of the atoms at a high temperature allows a measure of self-annealing to take place even during the moment of quenching. When the transformation temperature was lower the α lines were sharp after slow-cooling but usually diffuse after quenching from the γ state.

The body-centred cubic lines were sharp when the α phase was produced by a slow reaction at a low temperature, but diffuse when produced by a rapid transformation. For example, certain alloys may be converted from the γ to the α form either by plunging in liquid air or by prolonged heating at 300–350° C. The former experiment gives broad lines, the latter sharp lines.

These facts show that it is possible in many cases to decide whether the body-centred cubic phase was present before quenching or was produced during this process.

Account of the X-Ray Powder Photographs.

In the following paragraphs a summary is given of the most important conclusions to be drawn from each group of experiments.

The γ–α Transformation.—On rapidly cooling alloys with less than 20% of nickel to room temperature from the γ state, spontaneous transformation to the α form takes place. The transformation can only be suppressed completely when there is more than 20% of nickel present. For example, on quenching alloys containing less than 20% of nickel from 900° C., the transformation is complete, the X-ray powder photograph showing only diffuse body-centred cubic lines. The lines tend to broaden as the nickel content rises.

Heterogeneous Alloys.—Specimens cooled more slowly tend to show traces of the face-centred cubic structure mixed with the body-centred cubic structure. In general, the slower the cooling rate the sharper are the body-centred cubic lines and the greater is the amount of face-centred cubic structure which is retained. For example, alloys lump-annealed at 1300° C. and cooled at 10° C. per hr. show a certain amount of the face-centred cubic structure in all alloys containing more than 6% of nickel. The lines are much sharper than after quenching in the case of the low-nickel alloys, but the 16% nickel alloy is only partially changed, the lines remaining very diffuse and the structure almost completely body-centred cubic.

The Effect of Liquid Air.—On immersion in liquid air the effects of slow cooling were partially reversed, the amount of the face-centred cubic phase being in most cases considerably reduced. An alloy with 29% of nickel, which was pure face-centred cubic both after quenching and after slow cooling, was largely converted to the body-centred cubic form by immersion in liquid air. The proportion transformed was the same after the alloy had warmed up to room temperature.

The Development of a Two-Phase Structure by Annealing below 600° C.—It was pointed out by Owen and Yates [6] that lump-annealing just below 600° C. had the effect of sharpening the X-ray reflections. The present authors therefore made a comparison of the effects of lump-annealing at 700° and 570° C. The results were most surprising. Lump-annealing at 700° C. gave just the same results as if the alloys had only been heated at 1300°; lump-annealing at 570° C. for nine days gave entirely different results. Not only were the reflections very much sharper, but the proportion of the face-centred cubic structure was in nearly every case much greater.

In previous experiments there had been no regularity in the sequence of the results. This was completely rectified by lump-annealing at 570° C. Slowly-cooled powders now gave a very consistent series of photographs. The proportion of α to γ steadily fell from 6% nickel, which was pure α, to 29%, which was practically pure γ. Intermediate alloys all fell into line, proving that there was a normal two-phase range extending from about 6% nickel to about 29% nickel.

A Transformation at 580° C.—Filings from lumps annealed at 570° C. were subjected to three types of heat treatment designed in order to find out whether there was an upper temperature limit to the two-phase $\alpha + \gamma$ range. Photographs of filings quenched from 650° and 610° C. proved that this was the case. The effect of lump-annealing at 570° C. had been completely eliminated. Alloys containing 16% of nickel were no longer heterogeneous. As in the case of alloys quenched from 900° C., the structure was martensitic, *i.e.*, it had been face-centred cubic before quenching but was converted to body-centred cubic at the moment of cooling to room

temperature. This was shown by the very diffuse nature of the lines. Alloys containing more than 20% of nickel retained a face-centred cubic structure after quenching. In short, all iron-nickel alloys with more than about 12% of nickel are pure γ above 580° C. The state of alloys with less than 12% of nickel is less clear, but will be discussed again at a later stage.

Filings quenched from 570° C. gave a two-phase sequence between about 7 and 23% of nickel. This two-phase range evidently begins suddenly on cooling from 610° to 570° C. Since the lines are still somewhat lacking in sharpness, it appears that the transformation has scarcely been completed at 570° C. The transformation temperature is therefore put at 580 ± 10° C.

The $\alpha + \gamma$ Range at 450° C.—The effect of heat treatment at 570° C. in producing a well-defined range of two-phase alloys can be paralleled at 450° C. Preliminary experiments had shown that the alloys were becoming very sluggish at this temperature. It was therefore decided to give heat treatment for a month, in powder form. The powder photographs now presented a close resemblance to those of the slowly-cooled series, lump-annealed in the same manner. The results showed an even higher degree of consistency, the proportion of the body-centred cubic structure decreasing steadily from 7·6 to 26% of nickel. The traces of α present in the 26 and 29% alloys after cooling must be ascribed to the fact that these were not quenched after heat treatment.

After quenching filings from 610° C. in order to destroy their two-phase character, they were again heated at 450° C. for one month. The results were so similar to those of the previous experiment that there can be no doubt that the equilibrium conditions at 450° C. have been satisfactorily established. Further confirmation was obtained by plunging filings in liquid air before heating at 450° for one month. Again the results were substantially identical with the previous series.

A Transformation at 350° C.—The experiments just described show that equilibrium at 450° C. is not very different from equilibrium at 570° C. The next series of heat treatments was designed in order to test the equilibria at lower temperatures. Three separate experiments were made. First, filings were heated for one month at about 350° C., the lumps having previously been annealed at 570° C. Next, the filings were quenched from 610° C. before heating for one month at 350° C. Finally, filings were heated for one month at 325° C. after previous treatment in lump form at 550° C. Quite unexpected results were obtained in these experiments.

Alloys containing from 8 to 25% of nickel were largely converted to the α form by heat treatment at the lower temperatures, and no longer showed the orderly sequence of $\alpha + \gamma$ structures. Moreover, alloys with greater nickel contents, which contained only γ structures at higher temperatures, now became two-phase. In fact, the two-phase region is abruptly displaced to a much higher nickel content.

The first and last of the three series of experiments gave the most striking results. The times of heat treatment were inadequate to give complete equilibrium at these low temperatures. Experiments are now under way in which filings are being heated for at least six months; it is hoped that a fairly complete approach to equilibrium will be obtained in this time. The results so far obtained though only partially on the way to equilibrium, are enough to show the nature of the transformations which are taking place.

Alloys with less than 25% of nickel are becoming purely body-centred cubic. For example, one with 20% of nickel contained only 35% of the body-centred cubic structure after a month at 450° C., but after a month at 350° C. 80% of the structure was body-centred cubic. It is not unreasonable to suppose that prolonged heating at the lower temperature would have completed the conversion. At 325° C., the alloy being still more sluggish, only 75% had been converted to the body-centred cubic form after a month.

An alloy with 23% of nickel which was 90% face-centred cubic after a month at 450° C. became 75% body-centred after a month at 350° C. It is probable that all alloys with less than 25% of nickel would become purely body-centred cubic after prolonged heating between 325° and 350° C.

The case of the 26% nickel alloy is particularly interesting. It is worth while to compare its behaviour under different conditions. After quenching from either 610° or 570° C. it contained only the face-centred cubic structure. At 450° C. a slight amount of the body-centred form appeared; this alloy is probably near the boundary of the γ phase at 350–450° C. After heating at 350° C., 65% was converted to the body-centred cubic form.

By contrast, filings of this alloy quenched from 610° C. and then heated at 350° C. contained only a trace of the body-centred cubic form. In fact, the result was practically the same as if the alloy had been heated at 450° C. after quenching from 610° C. The result of heat treatment at 350° C. was therefore found to be dependent on the previous history of the alloy. The most probable explanation is that the transformation temperature is so close to 350° C. as to make the exact course of the reaction extremely critical, especially since the authors' temperature control was not very precise, the possible fluctuations amounting to at least $\pm$ 10° C. Further experiments are now being carried out in which specimens are being heated for six months at 330° and 370° C. This should prove definitely whether the transformation occurs between these two temperatures.

Equilibrium below 350° C.—While alloys with less than 25% of nickel gradually change to body-centred cubic on heating at 325–350° C., those with more nickel become two-phase. As far as the authors can tell from the present inadequate times of heat treatment, the solubility limit just below 350° C. is at about 32% nickel, whereas that at 325° C. is at about 40% nickel. For example, there

was 35% of the body-centred cubic phase after heating the 29% alloy at 350°, and 50% after heating at 325° C.

The most surprising feature was the presence of about 15% of the body-centred cubic phase in the 35% nickel alloy after heating at 325° C. This is very near the composition of Invar, which has been shown by Phragmén to be pure face-centred cubic. It would now appear that Invar is a supersaturated solid solution, which may possibly account for its abnormal properties.

Conclusions.

It seems probable that complete equilibrium is attained in iron-nickel alloys above 450° C., provided that the times of heat treatment are adequate. Conditions differ according to the composition. Four distinct ranges can be recognised, as follows :

(*a*) 0–6% nickel.
(*b*) 6–25% nickel.
(*c*) 25–40% nickel.
(*d*) 40–100% nickel.

Results obtained in each composition range will now be summarised.

(*a*) The 0–6% nickel alloys are face-centred cubic at high temperatures, but change to body-centred cubic on cooling. The most direct X-ray evidence for these alloys is that found by Smith,[7] who took photographs in a high-temperature camera above and below the transition temperature. Smith's results are summarised in Table II. Smith found only face-centred cubic structures above the

TABLE II.—*Transfromation Temperatures of Iron-Nickel Alloys* (*Smith*[7]).

Composition in Weight-% of Nickel.	Transformation Temperatures.	
	On heating. ° C.	On cooling. ° C.
0	908	908
2·0	773	758
3·13	714	705
5·30	622	608

transition temperatures and only body-centred cubic structures below them. No evidence was found for two-phase regions. These results are in the main in good agreement with the microscopical evidence of D. and H. Hanson,[3] who found very similar temperatures for the transition, though separated by a definite two-phase region, which is of course more probable on theoretical grounds. The present authors have no direct evidence to add to this. X-ray photographs taken at room temperature always show

the body-centred cubic structure, owing to the spontaneous nature of the transformation.

(*b*) Alloys in the range 6–25% nickel can be obtained as single-phase alloys or as two-phase alloys, depending on the conditions of heat treatment. To obtain the two-phase structure they must be subjected to long periods of heat treatment between 350° and 580° C. Under these circumstances, the approximate composition of the body-centred cubic phase is 6%, that of the face-centred cubic phase about 25% of nickel. If the heat treatment is carried out above 580° C. the alloy becomes face-centred cubic, which changes almost completely to the deformed body-centred cubic form if cooled rapidly through the two-phase range. If the alloy contains less than 20% of nickel, cooling to room temperature is sufficient for this purpose; alloys with more than 20% of nickel may require more drastic cooling.

(*c*) Alloys in the range 25–40% nickel in some respects resemble those in the previous range. They are, however, converted to the two-phase state by heating below 350° C., but not at 450° C. Very many months are required to carry out this process to equilibrium, and normal cooling rates down to room temperature only give the pure face-centred cubic lattice. At the temperature of liquid air the face-centred structure may be wholly or partially transformed to the body-centred cubic state where the nickel content is less than about 30%.

The Proposed Equilibrium Diagram.

Fig. 1 gives a proposed equilibrium diagram, based upon the present experiments, except for the range 0–6% nickel, where Smith's results are incorporated.

The lower temperature limit of the γ phase field falls steadily from 908° C. for pure iron to about 580° C. for 6–7% nickel. It then remains constant or nearly so up to about 23% nickel. Following a rapid fall to about 350° C., the lower limit of γ again remains almost constant at this temperature up to about 40% nickel. This curve shows two discontinuities, the first at about 6–7% nickel at 580° C., the second at about 26% nickel at 350° C. It does not seem possible to draw smooth curves through these points, which must, therefore, represent definite reactions.

The α phase is confined to compositions below about 6–8% nickel. This is in agreement with the work of D. and H. Hanson. Their diagram failed to explain why alloys containing more nickel should be capable of complete transformation to the body-centred cubic form. The present diagram gets over this difficulty by the introduction of the new phase at 25% nickel. This phase, like α, has a body-centred cubic structure, but it is only formed below 350° C. or thereabouts. It seems probable that the new phase will have a superlattice—experiments are being carried out to test this hypothesis. It is significant that its composition is about Fe_3Ni. Un-

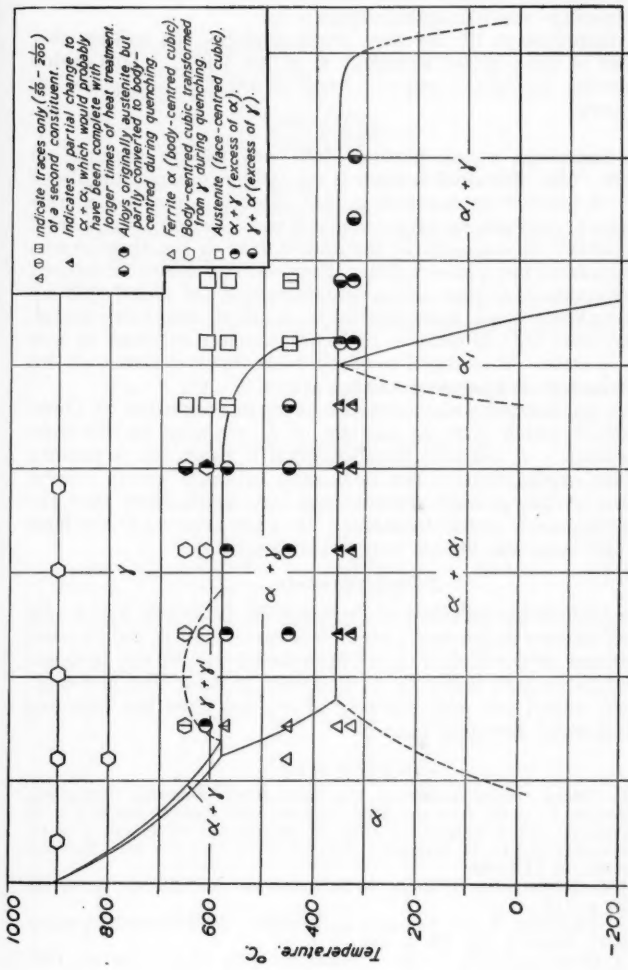

FIG. 1.—Iron-Nickel Equilibrium Diagram.

fortunately it is not possible to identify X-ray powder photographs in which two body-centred cubic structures are in equilibrium; the lattice spacings are too nearly equal.

The introduction of the new phase explains the sudden displacement of the γ-phase boundary at about 350° C. This is due to a reaction between α and γ. Representing the new phase by α_1, we have

$$\alpha_1 \rightleftharpoons \alpha + \gamma.$$

The two-phase region between 350° and 580° C. requires no comment. The abnormal feature is its sudden contraction above 580° C. A possible explanation is that there is a reaction at this temperature, α combining with γ to give a new γ' phase richer in iron. This possibility is suggested by the dotted lines on the diagram surrounding a small two-phase region. The positive evidence in support of this hypothesis is that alloys containing 10% of nickel split up into two phases much more readily than alloys with more nickel. The alloy with 16% of nickel is the most reluctant to break up into the $\alpha + \gamma$ state. It is hoped to obtain more direct evidence on this point from high-temperature photographs.

Since the foregoing was written a paper has appeared by Owen and Sully,[8] which gives an account of X-ray work on the iron-nickel system. A different phase diagram is given. It is possible that their explanation of the facts may be more nearly correct than that of the present authors, and it is emphasised that the present diagram is purely tentative. It is put forward in the hope that it will stimulate further experimental work.

Acknowledgments.

The authors are indebted to Professor W. L. Bragg, F.R.S., for his great interest in the work, which was carried out in the Physical Laboratories of the University of Manchester and at the National Physical Laboratory under Dr. C. H. Desch, F.R.S. The investigation was carried out with the help of a grant from the Iron and Steel Industrial Research Council.

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APPENDIX.—*X-Ray Powder Photographs.*

Key to Abbreviations.

b = body-centred cubic.
f = face-centred cubic.
s = sharp lines.
ms = moderately sharp lines.
md = moderately diffuse lines.
d = diffuse lines.
vd = very diffuse lines.
vvd = extremely diffuse lines.
} α doublets not resolved.
Brackets indicate that only a trace of the second constituent was present.

The above descriptions refer to the body-centred cubic lines; the face-centred cubic lines were always sharp or fairly sharp.

TABLE III.—*Series* 1. *A Comparison of the Effects of Slow and Rapid Cooling. No Lump-Annealing.*

(*a*) Filings were quenched from 900° C.
(*b*) Filings were quenched from 800° C.
(*c*) Filings were cooled from 900° C. in a few hours.
(*d*) Filings were cooled from 900° C. in a few days.

Nickel. Atomic-%.	X-Ray Lines after Quenching.		Probable Structure at 900° C.	X-Ray Lines after Quenching.		Probable Structure at 800° C.
	Structure.	Sharpness.		Structure.	Sharpness.	
	(*a*) *Quenched from* 900° *C.*			(*b*) *Quenched from* 800° *C.*		
2	*b*	*ms*	γ	...	...	...
6	*b*	*d*	γ	*b*	*vvd*	γ
10	*b*	*vd*	γ	...	...	...
15	*b*	*d*	γ	...	...	...
20	*b*	*d*	γ	...	...	...
27	...	...	...	*f*	...	γ
	X-Ray Lines after Cooling.					
	Structure.	Sharpness.		Structure.	Sharpness.	
	(c) *Furnace-Cooled.*			(d) *Slow-Cooled.*		
2	...	...		*b*	*s*	
6	...	...		*b*	*s*	
10	*b* (+*f*)	*md*		*b* + *f*	*ms*	
15	*b*	*d*		*b*	*d*	
20	*b*	*vd*		*b*	*vd*	
24	...	...		*b* (+*f*)	*vvd*	

TABLE IV.—*Series* 2. *Test of the Effect of Liquid-Air Treatment. Lump-Annealed at* 1300° *C.**

(*a*) Filings cooled at 10° C. per hr. from 900° C.
(*b*) Slowly cooled filings immersed in liquid air for ¾ hr.
(*c*) Special liquid-air treatment.

Nickel. Atomic-%.	X-Ray Lines at Room Temperature.			
	(*a*) Slow-Cooled.		(*b*) After Liquid Air.	
	Structure.	Sharpness.	Structure.	Sharpness.
3	*b*	*s*	...	...
6	*b*	*s*	...	...
7·5	*b* (+*f*)	*s*	...	...
9	*b* + *f*	*s*	*b* (+*f*)	*s*
11	*b* + *f*	*ms*	*b* (+*f*)	*ms*
12	*b* + *f*	*md*	*b* (+*f*)	*md*
13	*b* + *f*	*md*	*b* (+*f*)	*md*
16	*b* (+*f*)	*vvd*	...	...
29	*f*	...	*b* + *f*	*vd*

(*c*) *The Special Liquid-Air Treatment* had the same effect on the 29% alloy whether this was immersed for 5 min. or for 3 hr. The result was also the same whether the photograph was taken at liquid-air temperature or subsequently at room temperature.

* All alloys referred to in this and subsequent experiments were first lump-annealed at 1300° C. for 3 days to ensure homogeneity.

TABLE V.—*Series* 3. *Comparison of the Effect of Lump-Annealing Above and Below* 600° *C. Powders Slowly Cooled to Room Temperature from Lump-Annealing Temperatures.*

(*a*) After lump-annealing at 700° C. for 3 days.
(*b*) After lump-annealing at 570° C. for 9 days.

Nickel. Atomic-%.	X-Ray Lines.				% *b*.
	(*a*) Lump-Annealed at 700° C.		(*b*) Lump-Annealed at 570° C.		
	Structure.	Sharpness.	Structure.	Sharpness.	
6	*b*	*ms*	*b*	*ms*	100
7·5	*b* (+*f*)	*ms*	*b* (+*f*)	*vs*	98
9	*b* (+*f*)	*ms*	*b* + *f*	*s*	95
11	*b* + *f*	*md*	*b* + *f*	*s*	90
12	*b* + *f*	*md*	*b* + *f*	*ms*	80
13	*b* + *f*	*md*	*b* + *f*	*ms*	75
14	*b* + *f*	*d*	*b* + *f*	*ms*	70
16	*b* (+*f*)	*vvd*	*b* + *f*	*ms*	60
17	...	...	*b* + *f*	*ms*	55
20	...	...	*b* + *f*	*ms*	55
23	...	...	*f* + *b*	*md*	15
26	...	...	*f* + *b*	*d*	10
29	...	...	*f* (+*b*)	...	1

TABLE VI.—*Series* 4. *A Comparison of the Effects of Powder-Quenching Above and Below* 600° *C. Lump-Annealed at* 570° *C.*

Nickel. Atomic-%.	X-Ray Lines after Quenching.		% *b*.	Probable Structure—
	Structure.	Sharpness.		
	(a) *Filings quenched from* 650° *C.*			*At* 650° *C.*
6	*b* + *f*	*ms*	90	?
7·5	*b* + *f*	*ms*	98	?
12	*b* (+ *f*)	*d*	99	(γ ?)
16	*b*	*vvd*	100	γ
20	*f* + *b*	*vvd*	20	γ
23	*f*	...	0	γ
	(b) *Filings quenched from* 610° *C.*			*At* 610° *C.*
7·5	*b* + *f*	*ms*	95	?
12	*b* (+ *f*)	*d*	99	?
16	*b*	*vvd*	100	γ
20	*b* + *f*	*vvd*	80	γ
23	*f*	...	0	γ
26	*f*	...	0	γ
29	*f*	...	0	γ
	(c) *Filings quenched from* 570° *C.*			*At* 570° *C.*
7·5	*b* (+ *f*)	*vs*	98	α (+ γ)
12	*b* + *f*	*md*	90	α + γ
16	*b* + *f*	*d*	65	α + γ
20	*f* + *b*	*d*	35	γ + α
23	*f* (+ *b*)	...	1	γ (+ α)
26	*f*	...	0	γ
29	*f*	...	0	γ

TABLE VII.—*Series 5. A Test of the Effect of Prolonged Heating at 450° C. Lump-Annealed at 570° C.*

Nickel. Atomic-%.	X-Ray Lines at Room Temperature. Structure.	Sharpness.	% *b*.	Probable Structure at 450° C.
	(a) *Powders heated at 450° C. for 1 month.*			
7·5	*b* (+ *f*)	*vs*	99·5	α (+ γ)
12	*b* + *f*	*s*	80	α + γ
16	*b* + *f*	*ms*	55	α + γ
20	*f* + *b*	*ms*	35	γ + α
23	*f* + *b*	*md*	10	γ + α
26	*f* (+ *b*)	...	2	γ
29	*f* (+ *b*)	...	0·5	γ
	(b) *Powders heated at 450° C. for 1 month after quenching from 610° C.*			
7·5	*b* (+ *f*)	*vs*	99	α (+ γ)
12	*b* + *f*	*s*	80	α + γ
16	*b* + *f*	*ms*	65	α + γ
20	*f* + *b*	*md*	35	γ + α
23	*f* + *b*	...	5	γ + α
26	*f* (+ *b*)	...	0·5	γ
29	*f*	...	0	γ
	(c) *Powaers heated at 450° C. for 1 month after immersing in liquid air.*			
7·5	*b* (+ *f*)	*vs*	99	α (+ γ)
9	*b* + *f*	*vs*	95	α + γ
11	*b* + *f*	*s*	85	α + γ
12	*b* + *f*	*s*	80	α + γ
13	*b* + *f*	*s*	75	α + γ
14	*b* + *f*	*s*	65	α + γ
16	*b* + *f*	*s*	55	α + γ
17	*f* + *b*	*ms*	45	γ + α
20	*f* + *b*	*ms*	35	γ + α
23	*f* + *b*	*md*	10	γ + α
26	*f* (+ *b*)	...	3	γ (+ α)
29	*f* (+ *b*)	...	1	γ

TABLE VIII.—*Series 6. A Test of the Effects of Prolonged Heating at 350° and 325° C. Lump-Annealed at 570° C. for 9 days.*

Nickel. Atomic-%.	X-Ray Lines at Room Temperature. Structure.	Sharpness.	% *b*.	Probable Structure—
	(a) *Powders heated at about 350° C. for 1 month.*			*Just below 350° C.*
7·5	*b*	*s*	100	α
12	*b* + *f*	*ms*	95	α
16	*b* + *f*	*ms*	85	α
20	*b* + *f*	*md*	80	α
23	*b* + *f*	*md*	75	α
26	*b* + *f*	*d*	65	α + γ
29	*f* + *b*	*d*	35	γ + α
	(b) *Powders heated for 1 month at about 350° C. after quenching from 610° C.*			*Just above 350° C.*
7·5	*b* + *f*	*vs*	95	α + γ
12	*b* + *f*	*s*	75	α + γ
16	*b* + *f*	*ms*	80	α + γ
20	*b* + *f*	*d*	55	α + γ
23	*f* + *b*	...	10	γ + α
26	*f* + *b*	...	1	γ (+ α)
29	*f* + *b*	...	0·5	γ
	(c) *Powders heated for 1 month at 325° C. after quenching or slow cooling in lump (marked thus *) from 550° C.*			*At 325° C.*
7·5	*b*	*vs*	...	...
12	*b* + *f*	*s*	95	α
16	*b* + *f*	*s*	85	α
20	*b* + *f*	*s*	70	α
23	*b* + *f*	*ms*	60	α
25	*b* + *f*	*ms*	60†	α
26	*b* + *f*	*ms*	55	α + γ
29*	*b* + *f*	*ms*	50	α + γ
32*	*f* + *b*	*s*	35	γ + α
35*	*f* + *b*	*s*	15	γ + α

† After immersion in liquid air.

NIOBIUM-IRON ALLOYS.*

By R. GENDERS, M.B.E., D.Met., F.I.C., and R. HARRISON, B.Sc.
(Research Department, Woolwich).

(Figs. 3 to 29 = Plates I. to V.)

Synopsis.

The investigation comprises a study of the constitution of the niobium-iron system with particular reference to the phase changes occurring in the alloys of low niobium content. The phase diagram of the system is of the same type as that of tantalum-iron alloys. Up to 50% niobium the alloys may be considered as alloys of iron and a compound of composition approximating to Fe_3Nb_2. The solubility of this compound in α-iron is small at atmospheric temperatures but increases to 1·8% at the peritectoid temperature of 989° C.; its solubility in γ-iron increases with temperature from 1·0% at 989° C. to 2·0% at the eutectoid temperature of 1220° C. The data are complementary to the diagram of Eggers and Peter. Certain discrepancies are discussed.

The addition of niobium to iron produces effects similar to those of tantalum, namely, a progressive increase in hardness with increase in niobium content and susceptibility to temper-hardening when water-quenched alloys of suitable composition are reheated.

The properties of the niobium-iron alloys are of practical significance in connection with the industrial use of the metal as a constituent of weldable alloy steels and rapid-nitriding steels.

A previous investigation by the present authors, described in a paper on "Tantalum-Iron Alloys and Tantalum Steels,"[1] included some work on steels containing both of the sister elements tantalum and niobium. These results showed that the tantalum-iron system was of uncommon type and indicated that niobium probably formed a parallel system. A limited examination of the iron-niobium alloys was accordingly made, since no published information as to their constitution was available. Recently two papers on the subject have appeared.[2, 3] The first, by Vogel and Ergang,[2] appears to have been based on the deductions of Wever from atomic-radii curves, and assumed a closed γ field bounded by a single solid solution; changes in the solid state were not examined in detail. The more substantial paper by Eggers and Peter[3] gives an equilibrium diagram (Fig. 1) based on the results of thermal analysis and microscopical examination of over thirty alloys containing from 0·5 to 70% of niobium. The liquidus is in accordance with that of Vogel and Ergang; the solid phases, however, show no γ loop but

* Communication from Research Department, Woolwich, received March 3, 1939.

fall into a system of the same type as that of the tantalum-iron alloys. That portion of the diagram covering the dilute alloys, which are of most practical importance, is given only tentatively. In general the results of Eggers and Peter are in agreement with those obtained in the Research Department, Woolwich, over the range investigated, but there are certain differences and discrepancies described and discussed in the present communication, which also provides some data for the completion of the iron-rich end of the constitutional diagram.

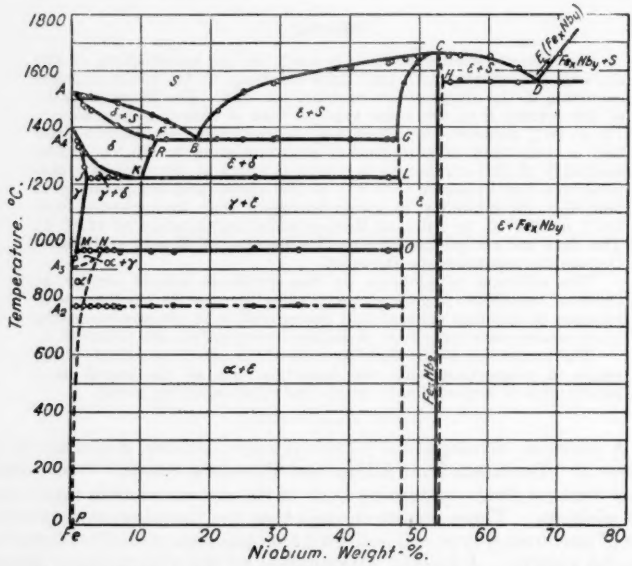

FIG. 1.—Niobium-Iron Diagram according to Eggers and Peter.

Preparation of the Alloys.—The alloys were prepared by melting electrolytic iron (99·95%) and commercially pure niobium (<99·5%), obtained as strips trimmed from the edges of sheet and as partly forged rod, in pure alumina crucibles in a high-frequency induction furnace, the general procedure being similar to that previously described for the preparation of tantalum-iron alloys. Twelve alloys containing up to 13·0% of niobium were melted in air and cast into iron moulds 1 in. in dia. by 5 in. long; a further six alloys for microscopical work containing from 0·4 to 1·4% of niobium and three alloys containing 16·4, 22·7 and 48·4%, respectively, were prepared by melting *in vacuo*, the vacuum being maintained

while the alloys were allowed to cool in the crucible. The first series of twelve alloys contained traces of silicon (average content 0·01%) and of lead, and most of the alloys contained some minute foreign inclusions which were difficult to distinguish from the iron-niobium compound particles precipitated on cooling from dilute solid solutions. No trace of aluminium was found in any of the alloys. The loss of niobium during melting was generally in the neighbourhood of 15–20% of the amount charged.

Thermal Analysis.—The thermal change points of the alloys containing up to 13% of niobium were determined by means of a platinum/platinum-rhodium thermocouple used in conjunction with a Carpenter-Stansfield potentiometer and Rosenhain plotting chronograph. The results obtained are given in Table I. The alloys containing up to 1·67% of niobium showed in the heating curves an Ac_3 change occurring over a range of temperature, the limits of which were difficult to define; the cooling curves, however, showed a recalescence at the beginning of this range, with a sharp end-point, and these indications were utilised in interpreting the heating curves.

TABLE I.—*Thermal Analysis of Niobium-Iron Alloys.*

Mark.	Niobium. %	Heating.		Cooling.	
		Lower Point. °C.	Upper Point. °C.	Upper Point. °C.	Lower Point. °C.
Electrolytic Iron	Nil	909	...	...	...
QAB 1	0·18	913–928	...	...	900–892
2	0·37	914–940	...	...	904–896
3	0·76	957–972	...	...	920–904
4	1·33	977–989	...	...	917–904
5 *	1·67	979–989	1270–1300	1161–1149	916–906
6	2·12	989	1211–1252	1158–1133	914
7	3·51	982	1210–1243	1151–1120	911
11	6·48	993	...	...	914
10	8·45	995	...	...	916
9	13·0	993	...	...	909

* In this alloy a slight absorption of heat on heating was observed also at about 1180–1200° C.

Maximum temperature for : lower point 1037° C.
upper point 1325° C.
Heating rate at : lower point 5–6° C. per min.
upper point 6–9° C. ,,
Cooling rate at : upper point 6–3·5° C. ,,
lower point 7–4° C. ,,

The results are also shown in the phase diagram in Fig. 2, which includes also the boundaries indicated by the microscopical work. The thermal points fall into a type of diagram similar to that of the

tantalum-iron alloys and are in most respects near to those of Eggers and Peter. The effect of alloying niobium with iron is to raise the temperature of the A_3 point from 909° to 989° C. at a content of 1·0% of niobium, the phase boundary remaining horizontal at higher concentrations. The existence of the $\alpha + \gamma$ field was indicated by the double thermal arrest in curves on alloys containing up to 1·67% of niobium. The points observed at higher temperatures relating to the eutectoid and the $\delta + \gamma$ range are in agreement

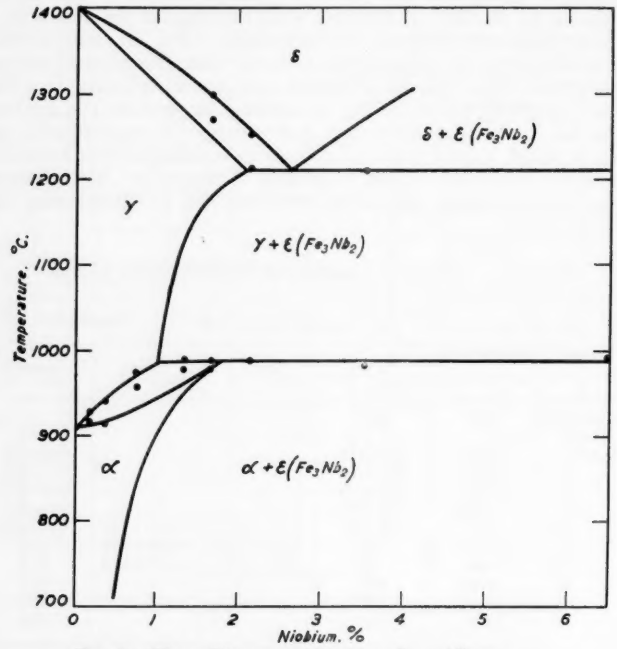

FIG. 2.—Phase Diagram of Niobium-Iron Alloys.

with those of Eggers and Peter, but are interpreted rather differently in view of the microscopic evidence.

Microstructure.—The microstructural features of the niobium-iron alloys are closely similar to those of the tantalum-iron alloys. In both systems a eutectic is formed between a compound ε (Fe_3Nb_2 and Fe_2Ta, respectively) and δ solid solution, the latter being resolved by a eutectoid transformation into $\gamma + \varepsilon$, which is transformed at a lower temperature into $\alpha + \varepsilon$ with connected changes in solubility.

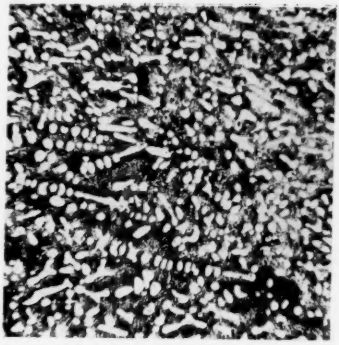

FIG. 3.—16·4% Niobium. Solidified and cooled in crucible. Primary δ and eutectic. × 100.

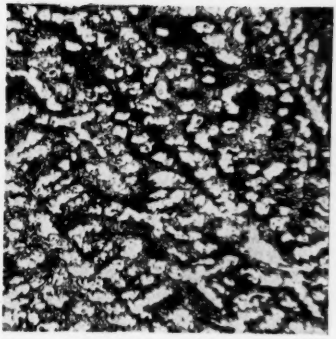

FIG. 4.—22·7% Niobium. Solidified and cooled in crucible. Primary ϵ and eutectic. × 100.

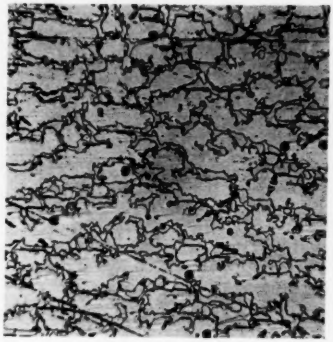

FIG. 5.—48·4% Niobium. Solidified and cooled in crucible. Mainly ϵ (Fe_3Nb_2). × 100.

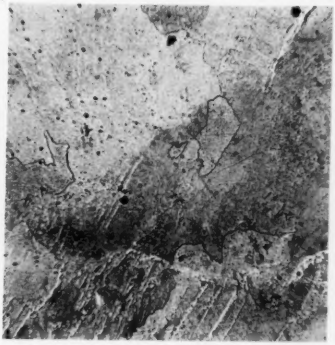

FIG. 6.—2·1% Niobium. Eutectoid with small amount of solid solution. × 100.

FIG. 7.—As Fig. 6. × 500.

[*Genders & Harrison.*
[*To face p.* 32 P.

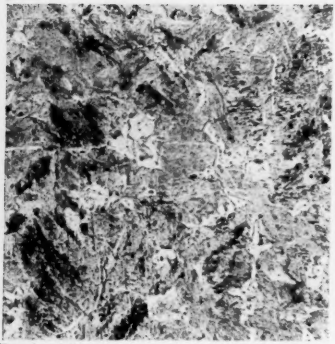

FIG. 8.—3·5% Niobium. Eutectoid with excess ϵ. × 100.

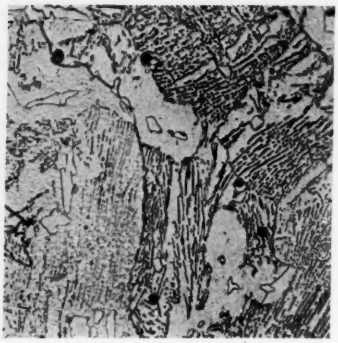

FIG. 9.—As Fig. 8. × 500.

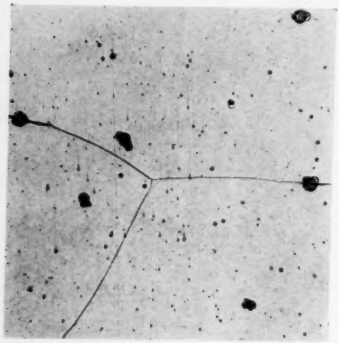

FIG. 10.—2·1% Niobium. W.Q. from 1270° C. × 100.

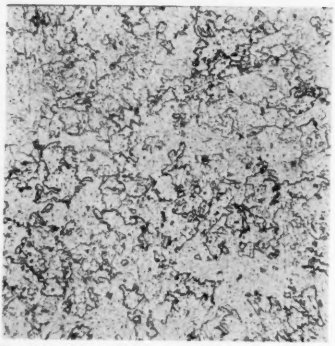

FIG. 11.—2·1% Niobium. W.Q. from 1220° C. × 100.

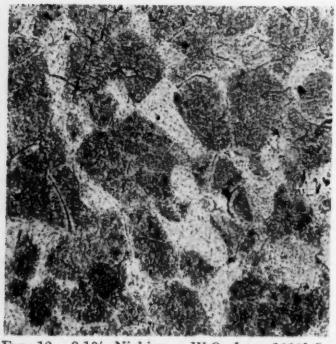

FIG. 12.—2·1% Niobium. W.Q. from 1220° C., reheated to 1120° C. and W.Q. Precipitation from differently concentrated δ and γ areas existing at 1220° C. × 100.

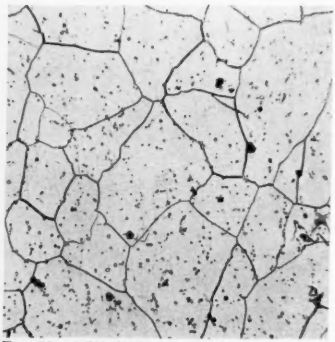

FIG. 13.—3·5% Niobium. W.Q. from 1270° C. × 100.

[*Genders & Harrison.*

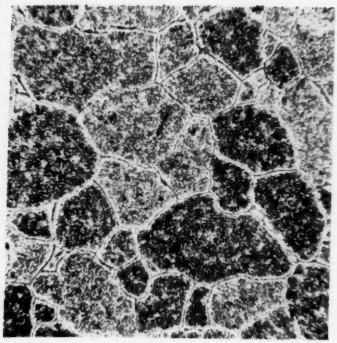

FIG. 14.—3·5% Niobium. W.Q. from 1270° C., reheated to 950° C. and W.Q. Precipitation of ϵ. × 100.

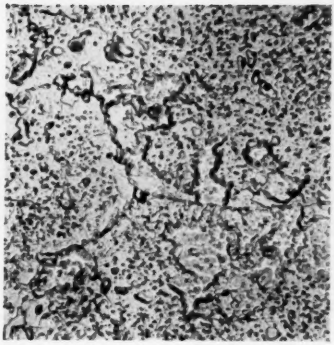

FIG. 15.—3·5% Niobium. W.Q. from 1270° C., reheated to 1100° C. and W.Q. × 500.

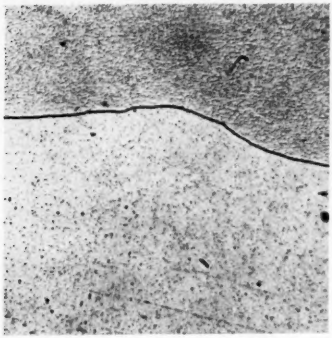

FIG. 16.—0·36% Niobium. Cooled slowly from 1270° C. × 500.

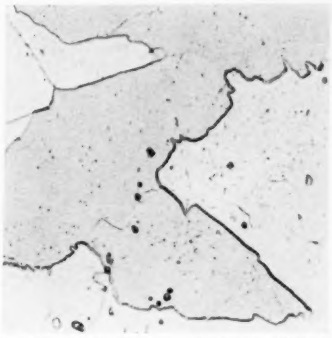

FIG. 17.—0·36% Niobium. W.Q. from 962° C. × 500.

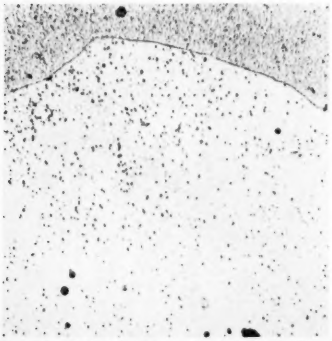

FIG. 18.—0·76% Niobium. Cooled slowly from 1270° C. × 500.

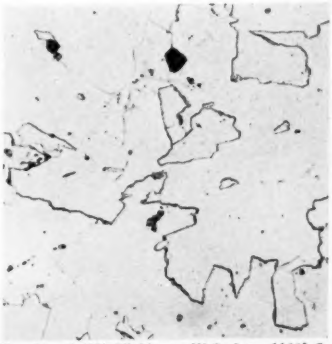

FIG. 19.—0·76% Niobium. W.Q. from 1180° C. × 500.

[*Genders & Harrison.*

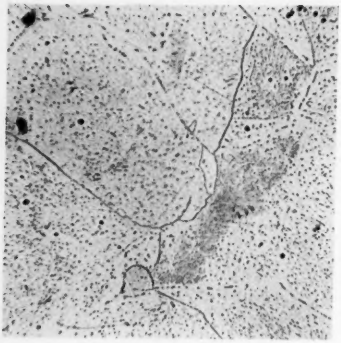

FIG. 20.—1·3% Niobium. Cooled slowly from 1200° C. × 100.

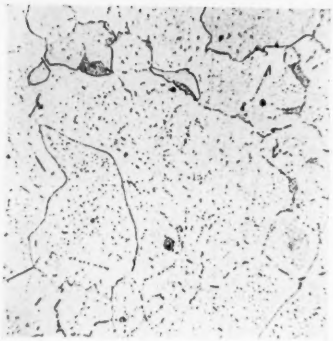

FIG. 21.—1·3% Niobium. W.Q. from 932° C. × 100.

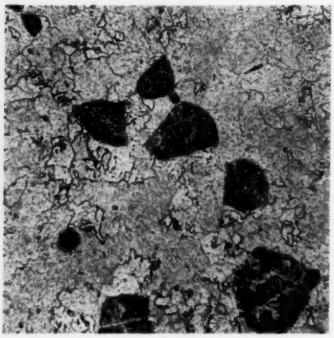

FIG. 22.—1·3% Niobium. W.Q. from 1000° C. × 100.

FIG. 23.—1·3% Niobium. W.Q. from 1180° C. × 500.

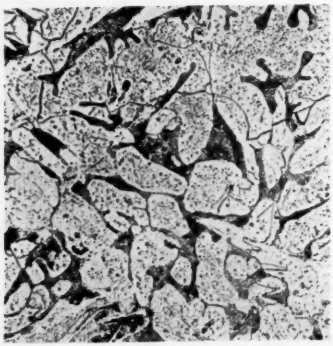

FIG. 24.—1·67% Niobium. Cooled slowly from 1270° C. × 100.

[*Genders & Harrison.*

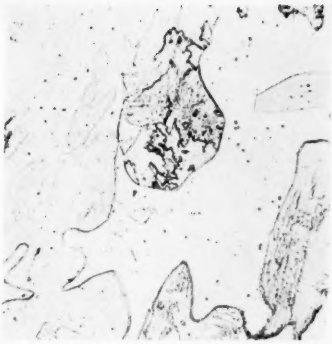

FIG. 25.—1·67% Niobium. Heated to 1270° C., cooled to 1200° C. (above Ar point) and W.Q., showing $\delta + \gamma$ existing at 1270° C. × 100.

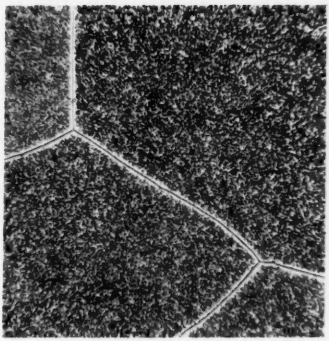

FIG. 26.—1·67% Niobium. W.Q. from 1270° C., reheated to 950° C. and W.Q. Precipitation of ϵ below peritectoid. × 100.

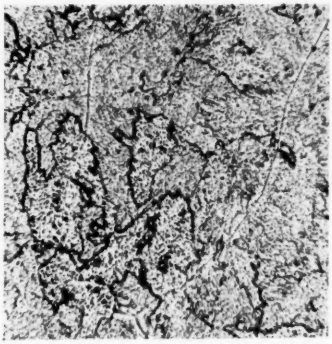

FIG. 27.—1·67% Niobium. W.Q. from 1270° C., reheated to 1050° C. and W.Q. Partial solution of ϵ in γ. × 100.

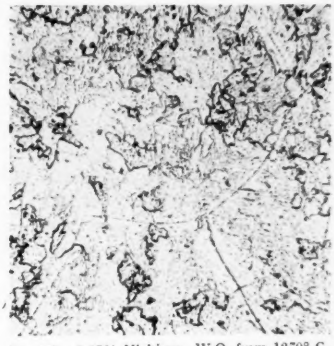

FIG. 28.—1·67% Niobium. W.Q. from 1270° C., reheated to 1100° C. and W.Q. Further solution of ϵ in γ as compared with Fig. 27. × 100.

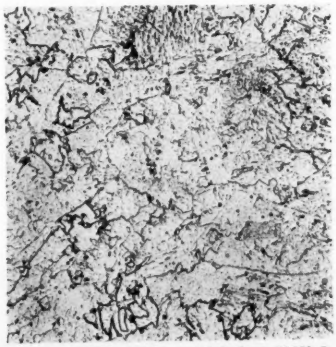

FIG. 29.—1·67% Niobium. W.Q. from 1175° C. Nearly complete solution of ϵ in γ. × 100.

[*Genders & Harrison.*

The Liquidus.—Microstructures of alloys slowly cooled in the crucible were in good agreement with the liquidus given by Eggers and Peter. The 16·4% alloy, Fig. 3, consisted of eutectic and dendrites of primary δ, while the 22·7% alloy, Fig. 4, showed a considerable amount of excess ε. The eutectic composition in the neighbourhood of 18% was thus confirmed. The 48·4% alloy, Fig. 5, consisted nearly entirely of ε compound, which was thus near the composition expressed by Fe_3Nb_2, the formula suggested by Eggers and Peter.

The Eutectoid Transformation.—The boundaries of the δ phase were, on the basis of the thermal and microscopical evidence, drawn to meet the eutectoid horizontal at approximately 2·6% niobium, a figure differing considerably from that of 10·0% given by Eggers and Peter. The position of the point was determined by the structures of two alloys containing 2·1% and 3·5% of niobium, respectively. The alloys slowly cooled from 1270° C. are shown in Figs. 6 to 9. The 2·1% alloy consisted almost entirely of eutectoid except for fringes of α solid solution, while the 3·5% alloy contained excess ε. The 2·1% alloy on quenching from 1270° C. was homogeneous, Fig. 10. Quenching from 1220° C.—*i.e.*, in the $\delta + \gamma$ range—gave a structure partly consisting of serrated boundaries typical of quenched γ, Fig. 11, which on reheating at 1120° C. (Fig. 12) showed variable density of precipitation, confirming that the initial quenching temperature had been within the duplex $\delta + \gamma$ region. The 3·5% alloy was nearly homogeneous at 1270° C. but contained small particles of undissolved ε (Fig. 13), and had, therefore, been quenched from just inside a duplex field. It showed an entire absence of evidence that γ had been present at 1270° C. and it may thus be concluded that the duplex field was $\delta + \varepsilon$. The quenched structure gave, on reheating to 950° C. (Fig. 14), a uniform dense precipitation of ε, and on again reheating to 1100° C. the structure was characteristic of $\gamma +$ precipitated ε (Fig. 15).

The method of determining the eutectoid point followed by Eggers and Peter was to examine a series of alloys quenched from just below the eutectoid horizontal. Their micrographs thus show, with increasing percentages of niobium, only an increase in the amount of spheroidised ε particles, from which it does not appear possible to estimate the eutectoid proportions. Further, the slowly-cooled structures given by Eggers and Peter appear to be less in agreement with their value of 10% than with that of 2·6% observed in the present work. It may be noted that the value of 2·6% gives a eutectoid of approximately the same atomic composition as that found for tantalum-iron alloys.

α- and γ-Phase Boundaries.—The positions of these boundaries were fixed approximately by microscopical examination of several alloys of low niobium content.

The solid solubility of ε in α at low temperatures was found to be

small and below 0·36% of niobium. Figs. 16 and 17 show the 0·36% alloy as annealed and after quenching from just inside the pure γ field. The roughened boundaries in Fig. 17, due to the $\gamma \rightarrow \alpha$ transition, are characteristic of specimens quenched from the γ field.

A 0·76% niobium alloy shows an appreciably greater amount of ε particles after annealing, Figs. 18 and 19. The position of the $\gamma + \alpha$ field was confirmed by a 0·86% alloy which showed similar complete solution of ε on quenching from 962° C., with some characteristic quenched γ boundaries.

A 1·3% alloy in the annealed condition showed a further increase of ε, Fig. 20, which was considerably reduced by heating at 932° C., indicating an increase in solubility with rise in temperature (Fig. 21). On heating to just above the peritectoid temperature at 1000° C. the structure showed, as indicated in the diagram Fig. 2, that the progressive change of α to γ is accompanied by a sudden change in the solubility of ε in α and γ, the excess ε being again precipitated from the γ and redissolved in the remaining α. On passing the boundary horizontal, all excess ε is precipitated, the last portions to change from α to γ showing a higher content of ε particles (Fig. 22). Heating to 1180° C. proved (Fig. 23) that solution of ε in γ is complete at this temperature and composition.

The 1·67% alloy was of particular interest, giving a range of structures on heat treatment which further illustrate the complexity of the changes in the system. The annealed alloy (Fig. 24), although beyond the eutectoid horizontal of the diagram as indicated by thermal measurement, contained areas of eutectoid. A similar discrepancy between the results of thermal analysis and of micro-examination was noted also by Eggers and Peter. The position of the $\delta + \gamma$ field was confirmed by Fig. 25, which illustrates the structure after heating at 1270° C. for 1½ hr. before cooling slowly to 1200° C. and then quenching in water. While the γ portion of the structure shows the characteristic rough boundary produced by the $\gamma \rightarrow \alpha$ change on rapid cooling, the δ, which has the same atomic structure as α, gives no visible indication of the changes $\delta \rightarrow \gamma \rightarrow \alpha$ and appears as a clear background to the γ grains. The specimen also illustrates the large thermal hysteresis in the alloys,* the structure on quenching from 1200° C. being the same as that quenched from 1270° C., the $\delta \rightarrow \gamma$ change on cooling only commencing at 1160° C. On heating the quenched specimen to 950° C. ($\alpha + \varepsilon$ range) ε is precipitated (Fig. 26), and by heating a similar specimen to 1050° C. ($\gamma + \varepsilon$ range) the structure is transformed into characteristic quenched γ with fine particles of precipitated ε (Fig. 27). At a still higher temperature (1100° C.) the γ is more concentrated and the ε particles diminish in quantity (Fig. 28), and at 1175° C.

* This feature was further confirmed with a eutectoid alloy which showed no eutectoid in specimens cooled in the furnace from within the δ field to temperatures above 1130° C. before quenching in water.

(Fig. 29) only slight traces of ε remain. These observations confirm the position of the γ boundary at about 1180° C. for 1·67% of niobium, and are in accordance with the slight heat absorption noted on the thermal heating curves. The "ghost" boundaries of the pre-existing δ crystals are visible in the latter two structures.

The micrographic evidence obtained from a number of low-niobium alloys thus agrees closely with the phase boundaries given

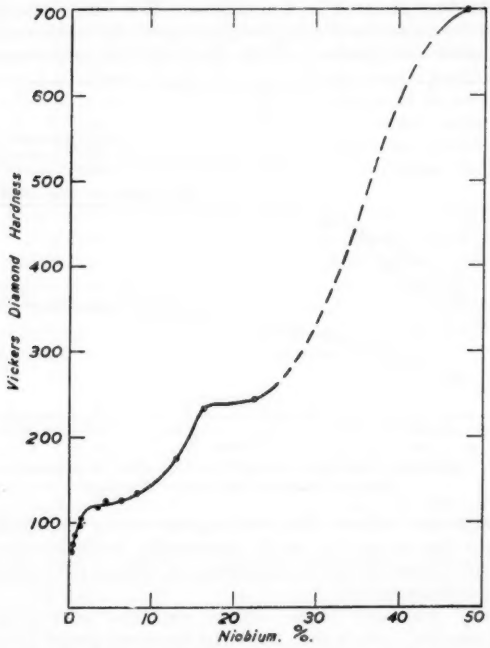

FIG. 30.—Effect of Niobium Content on the Hardness of Annealed Alloys.

in the diagram Fig. 2, which completes in detail the diagram given by Eggers and Peter.

Hardness of the Niobium-Iron Alloys.—Diamond hardness tests (Vickers) were made on small sections of a series of alloys after annealing by slow-cooling from 1250° C. The results given in the curve in Fig. 30 show that successive additions of niobium produce a progressive increase in hardness up to about 700 Vickers diamond hardness. The rate of increase in hardness is not constant, showing ranges over which the change with increase in niobium content is

small. These ranges coincide with the alloys in which eutectoid and eutectic, respectively, are dominant in the microstructure. The results are also recorded in Fig. 31 together with those of tests on the quenched alloys and after quenching and reheating to 700° C. The quenched alloys give, up to a content of 1·5% of niobium, an increase in hardness due to an increasing degree of supersaturation in the α solid solution. The reheated specimens showed that temper-hardening due to precipitation of ε occurs at 700° C. in alloys containing above 1% of niobium. This limit coincides with the γ phase boundary and may indicate some connection of temper-hardening with that phase. While the practical importance of the

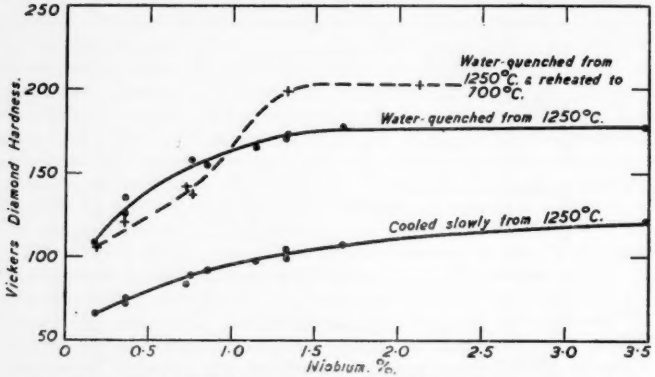

FIG. 31.—Effect of Niobium Content and of Heat Treatment on the Vickers Diamond Hardness Number.

pure niobium-iron alloys does not appear to be appreciable, the system provides scope for much interesting work on the relation of the γ and α boundaries to precipitation effects, particularly when applied to ternary alloys.

Nitriding Niobium Steels.—Work on this subject is to be published shortly. As a link with the previous paper on tantalum steels, however, it may be mentioned that niobium possesses advantages over tantalum as a constituent of nitriding steels.

Niobium Steels.—The constitution of the niobium-iron-carbon alloys has been dealt with by Eggers and Peter in a paper accompanying their work on niobium-iron alloys.[4]

Summary and Conclusions.

The niobium-iron alloys containing up to 50% of niobium may be considered as an alloy system of iron and the compound Fe_3Nb_2. A eutectic of the solid solutions δ and Fe_3Nb_2 (ε) is formed at a composition of about 18% niobium.

The solubility of Fe_3Nb_2 in α-iron is small at room temperatures, below 0·36%, and increases to a content of about 1·8% at the peritectoid temperature of 989° C.

The solubility in γ-iron also increases with temperature from about 1·0% at 989° C. up to about 2% at the eutectoid temperature of 1220° C.

The addition of niobium to iron raises the hardness progressively. Solution of ε by heating and quenching produces a small increase in hardness, and alloys containing more than 1% of niobium are further hardened by tempering at 700° C. after quenching.

A phase diagram (Fig. 2) deduced from the thermal, microscopical and hardness characteristics of the alloys containing up to 6% of niobium is given. This diagram completes in detail that put forward by Eggers and Peter. Though in broad agreement with the work of those authors, the present data provide grounds for making some corrections in detail, as well as for filling in the portions which were previously only tentative.

The pure niobium-iron alloys have no present industrial significance. Niobium, however, is finding a growing field of use as a minor constituent of steels, and the information now available regarding the constitution of the binary alloys is a necessary basis for the further study of more complex materials, particularly those, such as nitriding steels, in which niobium is necessarily in excess of that required to absorb the carbon present.

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(3) H. Eggers and W. Peter : "The Iron-Niobium Equilibrium Diagram." *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1938, vol. 20, No. 15, p. 199.

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THE CAUSES OF "ROLL-MARKS" ON TINPLATE.*

By ROOSEVELT GRIFFITHS, M.Sc. (University College of Swansea).

(Figs. 3 to 7 = Plates VI. to VIII.)

Summary.

The defect arising in the production of tinplate known as "roll-marks" or "roll pick-up" is considered. The various contributing factors, such as method of working, roll camber and relative speeds of the rolls, are discussed.

The ultimate cause of the defect is ascribed to particles of material picked up by the rolls from the sheets due to accelerated slip occurring locally between a roll and a sheet; the pressure and velocity of this slip is sufficient to cause the particles of the sheet to become heated and "tacky." The evidence in support of this contention being the recrystallised character of the streaks or particles on the sheets.

The type of defect referred to in this paper as "roll mark," is also known in the tinplate trade under another name, as "roll-pick-up."

The appearance of the defect in the finished tin plate is that of a band of parallel elongated depressions, each about $\frac{1}{8}$ in. or more long, and $\frac{1}{32}$ in. deep, and extending, in many cases, along the whole length of the sheet. The band may cover the whole width of the sheet, but more often is restricted to a width of about 2–3 in., and is often found in two bands, each at a distance of about a third of the width of the sheet from each side.

These depressions are rough and irregular in outline, and do not "take" the tin coating readily, and are therefore sources of corrosion when the sheet is fabricated. Apart from this, the appearance of the sheet is ruined.

The defect is responsible for a "wastage" of sheets, which may, in certain works, amount to 15% or more of the output during some weeks, whilst other works suffer very little from this trouble. The defect has been troublesome for many years, and with changed conditions of operation of certain mills, such as the substitution of gas for coal for the firing of reheating furnaces, the defect has manifested itself in an intensified form.

It was obvious in the initial stages of the investigation that a number of factors were involved which contributed to this defect, and these have given rise to a number of theories as to the cause.

* Received June 1, 1939.

Section I.—Rolling Operations.

To obtain a clear understanding of the conditions under which the defect occurs, a brief review of the rolling operations involved in the production of tinplate in South Wales is necessary.

Five, or more, systems of rolling are in use, but only two to any extent. In all systems, the steel bar is delivered to the tinplate works in lengths varying from 14 to 17 ft., 8 to 12 in. wide, and of a definite thickness, denoted by the weight in pounds per linear foot, which may be 10 to 70 lb. The bars are cut up to definite lengths, depending on the width of the finished sheet, an allowance of $\frac{3}{8}$ in. or $\frac{1}{4}$ in. being given for shearing.

Five-Part or Welsh System.

In the Five-Part system, these bars, called "iron," are placed in the "bar iron" furnace, commonly called the "thick" furnace and heated for about 60 min. to a temperature of between 700° and 800° C. The bar is withdrawn and subjected to four, and sometimes five, passes through the "thick" iron rolls, or "roughing rolls." It is then returned to the furnace, when it is termed a "single." This furnace may be a part of the bar iron furnace, or a separate furnace for the purpose. After about 15 min. heating the single is withdrawn, given two or three passes and rolled out to about twice its length. It is then doubled and returned to the furnace; the product is now called "doubles." Following a further period of heating, the doubles are rolled out, and again doubled so that the doubled end coincides with the two loose ends. This end of the pack is then sheared in such a way that the doubled portion is cut off, so that all the ends of the sheets are free. The product is termed "fours." These are again heated, rolled, doubled and sheared, and become "eights." The eights are reheated, and finally rolled to the required length, and consequently the required thickness.

The other systems differ from the one described in that a "matching" operation is introduced.

Three-Part and Four-Part Systems.

In particular in two systems either two singles (three-part system) or two fours (four-part system) are placed one on the other and rolled out together. The rolled-out singles are doubled, becoming fours, and then follow the procedure first described in the five-part system to the eights stage, whilst in the four-part system, the two matched fours, now consisting of eights, are rolled to the final length in the one operation. Other systems are in operation to a much lesser extent, in one of which only one pair of rolls are used for the entire operation, and in another three pairs of rolls working in tandem. In the last system, the first pair of "rough-

ing " rolls, " roughs " down all the iron and rolls the singles. The intermediate pair deals with all the doubles and two-thirds of the fours, while the finishing pair deals with the remainder of the fours and all the eights. In this investigation most of the work has been concerned with the five-part system.

Rolls.

The rolls themselves will be dealt with first. They are made of cast iron without, in the majority of cases, the addition of any alloying element with the exception of perhaps a small percentage of molybdenum. The roll surface is chilled to a depth of approximately $\frac{3}{4}$ in. to $1\frac{1}{2}$ in., the lower figure being preferable.

The sizes of the rolls vary from 21 in. to about 30 in. in dia., and lengths from 26 in. to 30 in. or more. In practically all cases the rolls are arranged in a train of two or more, usually four, pairs on each side of the prime mover; four pairs of rolls making two units, each unit consisting of a roughing and finishing mill. All the bottom rolls are driven, the rolls in a train being connected by a " wobbler," whilst the top rolls are practically never driven. The exception to this arrangement of the train is where the pairs of rolls are in tandem, when the bottom roll of each pair is directly coupled to a separate flywheel by means of a box coupling. The speed differs slightly in different mills, and is about 33 r.p.m. The bodies of the rolls are " dressed " to a certain contour, so that the diameter at the centre is less than that at the ends; the degree of concavity depending on a number of factors which include (*a*) roll dimensions, (*b*) character of chill, (*c*) dimensions of sheets to be rolled and (*d*) working temperature of roll.

It is unnecessary to discuss these factors here, suffice it to say that a concavity is necessary to compensate for slight changes which are produced under working conditions. These conditions arise mainly as a result of temperature variations along the roll and of the deflection of the roll under the rolling loads. The temperature of the roll increases slightly from the ends towards the middle, and is of the order of 350° C.; under certain conditions this temperature may not be attained and in others may be exceeded by a margin of 25° C. The temperature of the rolls is increased owing to the heat absorbed from the metal which is being worked and owing to compression and friction. Heat is lost by the usual means of radiation, conduction and convection, but this natural dissipation can be accelerated or decreased by artificial means such as (*a*) water sprays on the necks and wobblers, (*b*) steam applied to the middle of the body of the roll, or (*c*) gas- or oil-flame heating to cause additional expansion of the roll. By these means the concavity can be controlled to a limited extent. Despite this control the amount of concavity changes during the week. At the beginning of the week, when the rolls are cold, the value is in the region of 0·009 to 0·01 in., decreasing in value when the rolls become

warmed up, until on Monday evening very little or no concavity exists. This condition continues until about Wednesday morning, when the effect of wear becomes apparent and the concavity increases in value during the remainder of the week, until it approaches a value of 0·023 in. or more on Saturday morning, when rolling is discontinued. Either artificial means, such as oil or gas burners, are employed at the commencement of the week to heat up the rolls, or the rolls are allowed to heat up naturally by the heat of compression and conduction from rolling the hot packs. If possible, these packs are narrow in width and of heavy gauge, so as to impart as much heat as possible to the middle of the rolls. Also, the packs are narrow to minimise variation in substance across the width. Some indication of the effects of the change in camber on the rolled material can be seen in the " tails " of the rolled pieces or " packs." The packs rolled at the beginning of the week have " ears," the size of which on subsequent packs gradually becomes less as the concavity decreases, but they reappear as the camber increases during the remainder of the week.

Furnaces.

The furnaces are fired by coal, gas or oil. Control of the air is more accurate in an oil- or gas-fired furnace, so that the amount of scale formed on the packs is less in these furnaces than that in coal-fired furnaces, although the atmospheric conditions in both types are kept as near reducing as possible.

Section II.—Experimental.

Investigation revealed the important fact that the defect of roll-marks did not manifest itself until some hours after the rolls had been in commission. This would occur on Monday evening if the rolling operations started with hot rolls on Monday morning. The trouble continued throughout Monday night and Tuesday, and eventually ceased on Tuesday night or Wednesday morning. For the remainder of the week conditions were normal. If, due to roll breakage, it was necessary to change a roll during the week, similar conditions prevailed, and the roll marks appeared on the sheets after an interval of time, to disappear subsequently after a day or so.

The type of steel rolled had a marked effect in that " basic " steel was more prone to develop the defect than " acid " steel.

Careful examination of the sheets rolled throughout the week revealed that, corresponding to the periods when roll-marks were prevalent, some of the sheets exhibited a rough appearance. Raised streaks of scale-covered metal were visible, which appeared to be attached to the underlying metal of the sheet. The dimensions of these streaks varied somewhat, but were approximately $\frac{1}{8}$ in. or

more long, and up to $\frac{1}{16}$ in. wide. At one end of many of the streaks was a slight depression. A metallographic examination of these streaks will be referred to in Section III.

It is the practice, when roll-marks become prevalent, to rub the surface of the roll with a grinding stone which is pressed against the roll-surface with the aid of a long handle, levered against a support. This is done in order to remove small projections which are attached to the surface of the rolls and which are continuously forming as the rolling operations proceed. These projections, if allowed to remain on the roll, would, of course, produce indentations or roll-marks on the sheets which subsequently pass between the rolls. It seemed reasonable to assume that the streaks formed the material from which the projections on the rolls were made.

In order to find an explanation of the formation of these streaks, it was necessary to study carefully the rolling operation. As stated previously, only the bottom roll is driven, and the top roll is therefore driven through the medium of the material between the two rolls. It was necessary, therefore, to have some information concerning the relative speeds of the top and bottom rolls under various conditions of working and idling.

Determination of Relative Roll Speeds.

For this purpose a piece of apparatus was set up, the fundamentals of which are illustrated diagrammatically in Fig. 1. A series of 16 contact studs in the form of a circle was set in each of two pieces of hard asbestos. Over these contacts swept an arm, which was attached to a spindle to the other end of which was fixed a hard lead cone. The contacts were connected in series, in such a way that an electrical circuit was completed when the rotating arm made contact with one of the studs. The electrical circuit consisted of an accumulator and an electro-magnet. To the pole-piece of the electro-magnet was attached an inked pen which recorded, each time the circuit was completed, on a strip of paper $1\frac{1}{2}$ in. wide, moved forward at a constant speed by means of a clockwork mechanism.

The cone was pressed into the conical recesses which are found in the ends of the rolls, and which are normally used for supporting the roll when being ground. A separate set of contacts and circuit were used for each roll, but both records were made on the same strip of paper simultaneously. To obtain records of the inside pair of rolls of a train, a wheel supported in the pit beneath the rolls was rolled in contact with the bottom roll. Suitable electrical contacts in this wheel indicated its revolutions. The ends of the top roll were free, and the cone method of dressing the contact arm could be used. Records were made of the revolutions of the rolls when rolling the various stages of the packs from singles to eights, a mark being made on the paper to indicate the moment of entering and exit of the piece or pack in the rolls.

Records were taken twice a day throughout a week on the same mill, and the same procedure adopted with other mills.

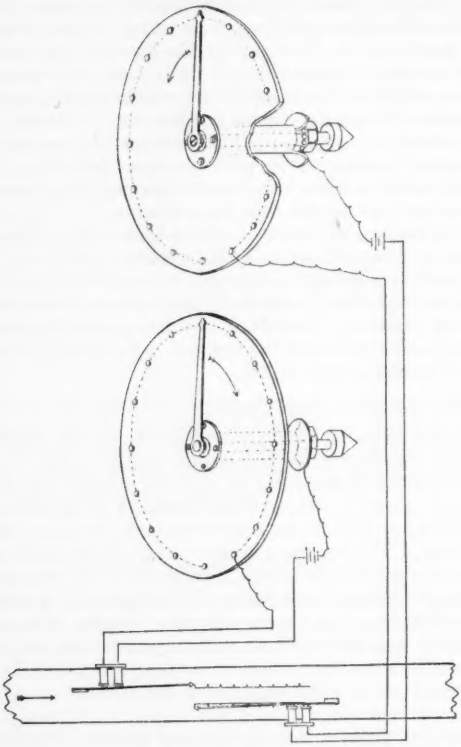

FIG. 1.—Diagram of Apparatus for the Determination of Relative Roll Speeds.

Results of Tests on Roll Speeds.

Some interesting facts emerged from these tests. A few typical records are shown in Figs. 2A, 2B and 2C which illustrate the results of tests made on the same mill on a Tuesday and Friday, and on a Tuesday on a mill in another works. It will be seen, on examination of these charts, that the entry of the stock had only a slight if any effect in lowering the speed of the rolls.

During the passage of the piece through the rolls there was also

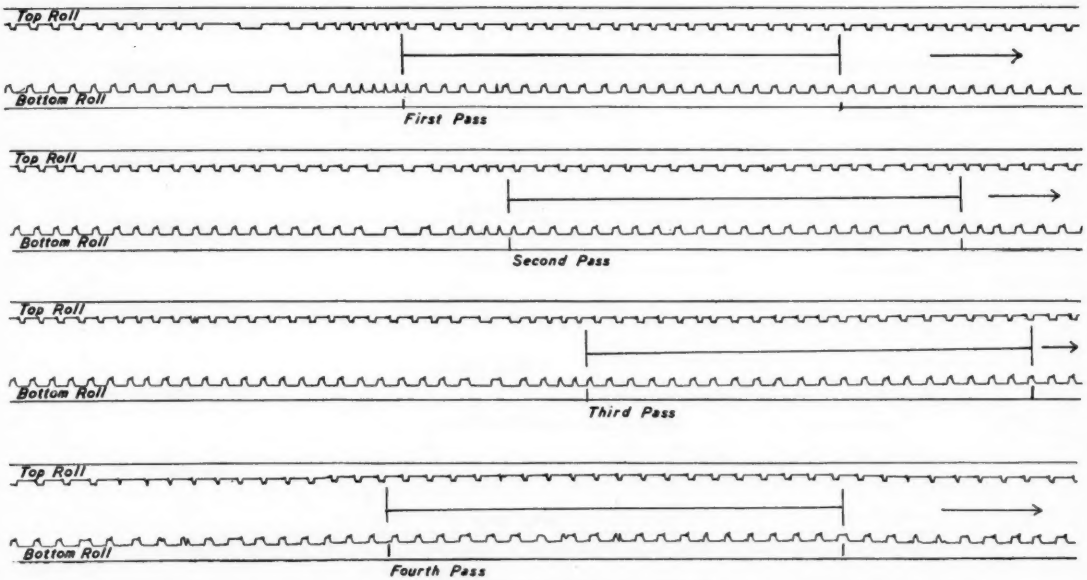

FIG. 2A (*see* Figs. 2B and 2C).—Records of the Relative Roll Speeds during the Passage of the Pack through the Rolls on Tuesday (works *A*).

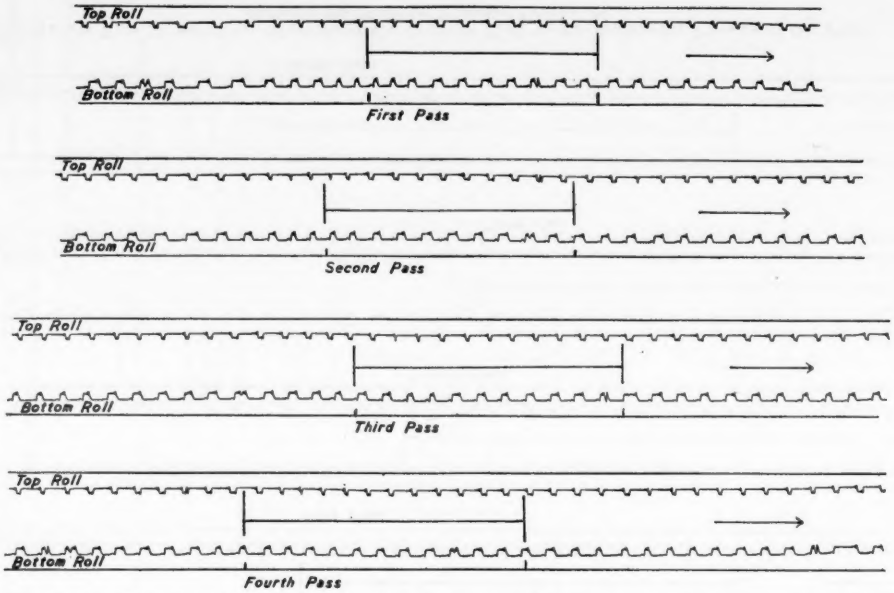

FIG. 2B (*see* Figs. 2A and 2C).—Records of the Relative Roll Speeds during the Passage of the Pack through the Rolls on Friday (works *A*).

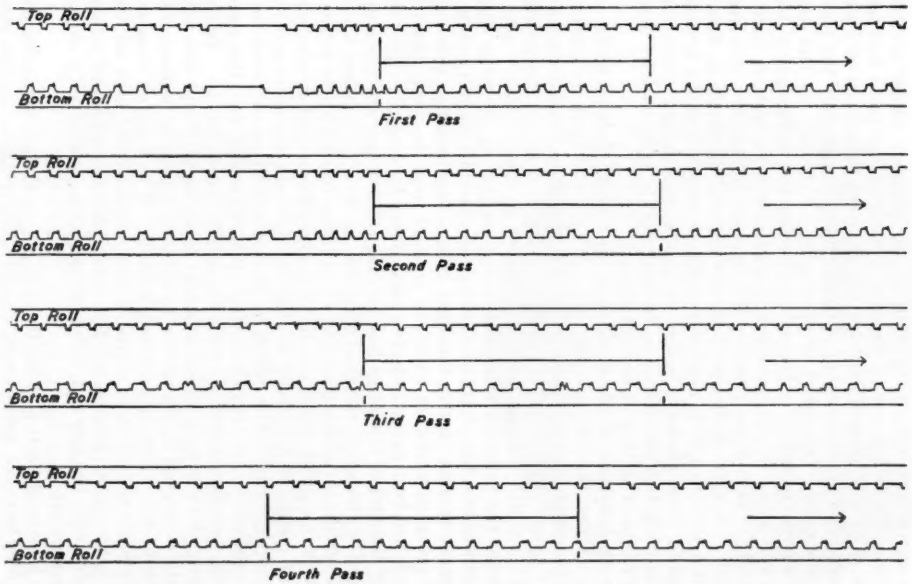

FIG. 2C (*see* Figs. 2A and 2B).—Records of the Relative Roll Speeds during the Passage of the Pack through the Rolls on Tuesday (works *B*).

little difference in the relative speeds of the top and bottom rolls, in some cases only was there a perceptibly lower speed of the top roll throughout the pass.

The significant fact, in relation to the problem under investigation, was the behaviour of the two rolls after the piece had left the rolls. As will be seen from Fig. 2A showing the record of Tuesday, there is an acceleration of both the rolls immediately the piece leaves the rolls. The effect is particularly apparent on the first pass of a stage of rolling. Immediately after this acceleration, the bottom roll slows down appreciably, and close observation during the operation sometimes revealed a complete momentary stoppage of the roll. A very short time later the top roll decreases in speed, whilst the bottom roll is now increasing in speed, but the bottom roll, almost immediately, suffers a slight retardation when the slower moving top roll comes in contact with it, followed by a regaining of speed to that of normal idling.

The explanation of these changes in speed appears to be as follows. When the rolls are flat, or nearly so, and have no camber, such as occurs at a period corresponding to Tuesday, the deformation of the " piece " in the roll is practically uniform across the greater part of its width. There is less tendency to form " ears," which result from the pressure being somewhat greater at the sides than at the centre in a longitudinal direction of the rolls when there is a pronounced camber in the finishing rolls. Incidentally, this subject of pressure variation over the contact area between the roll and stock has been investigated in great detail by Lueg.[1] Now the shape of the end of the piece last leaving the roll has an important effect on the change of speed of the rolls, in that, if the piece leaves the rolls suddenly, as happens when the end is rounded and without ears, there is a pinch effect on the rolls and also a sudden release of stored-up energy in the drive, so that the rolls are caused to accelerate or spin slightly. The result is that the bottom roll over-runs the drive slightly, but due to friction of the bearings, &c., the speed soon falls, sometimes to zero, until the drive again takes up. In the meantime, the top roll, which has also spun slightly and also subsequently decreased in speed due to friction, comes in contact with the bottom roll which is now accelerating. The top roll does not immediately take up the drive of the bottom roll, and relative motion takes place between the two rolls. In the process of coming in contact with the top roll, the bottom roll is momentarily slowed down somewhat.

The release of energy of the drive is not so violent when the end of the piece has ears, because the energy used in deforming the piece decreases in value to a lower figure when the ears pass between the rolls, and the stored-up energy of the drive has time to expend itself to a large extent. Nor is the release of energy so violent when the energy required for deformation is less, as is the case during the second and third pass compared with the first pass of the same

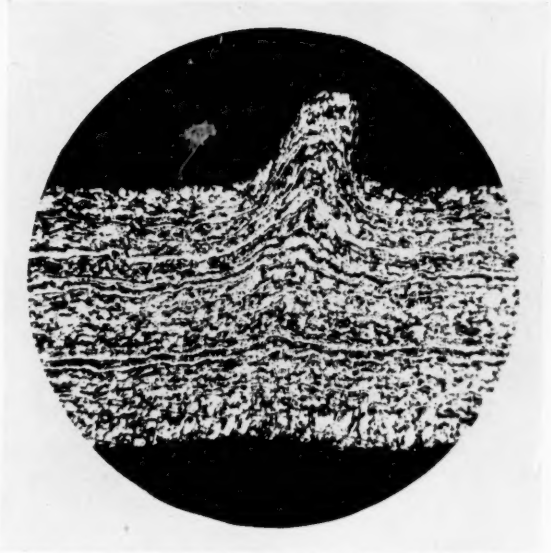

FIG. 3.—Section through Sheet and Streak at right angles to the direction of rolling. × 150.

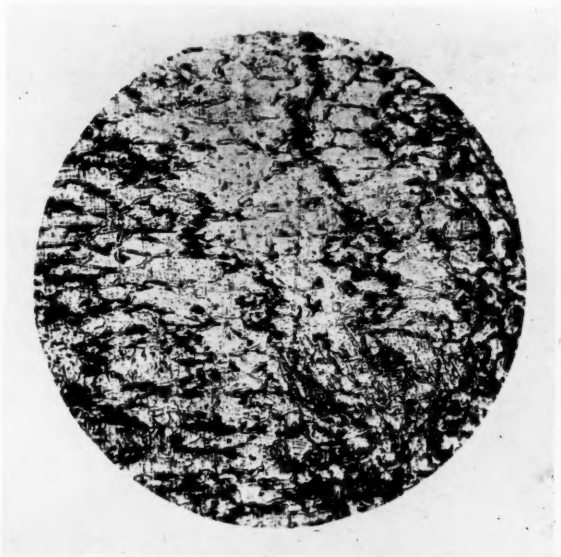

FIG. 4.—Structure of Sheet parallel to surface. × 175.
(Micrographs reduced to three-quarters linear in reproduction.)

[*Roosevelt Griffiths.*

[*To face p.* 48 P.

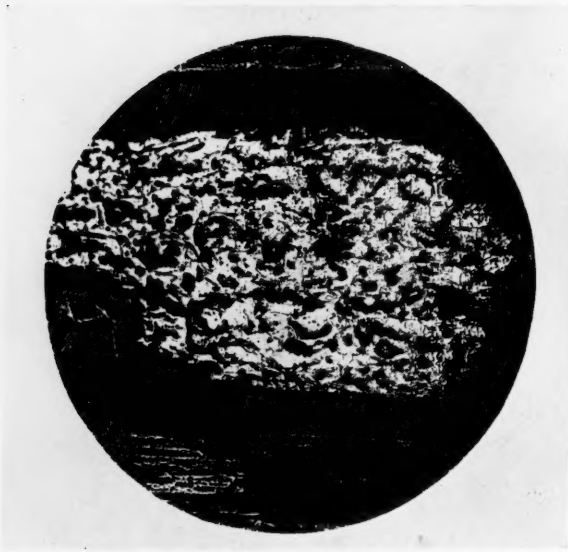

FIG. 5.—Structure of Streak parallel to surface of sheet. Dark areas, scale and cavities. × 175.

FIG. 6.—Section of Streak in direction of rolling. × 175.
(Micrographs reduced to three-quarters linear in reproduction.)

[*Roosevelt Griffiths.*

FIG. 7.—Section of Roll. Black streaks, cracks. × 175.
(Micrograph reduced to three-quarters linear in reproduction.)

[Roosevelt Griffiths.

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stage of rolling and similarly during the rolling of singles compared with the greater energy required to roll eights.

It must be emphasised that the result of the relative motion of the two rolls is that the roll surfaces are rubbed in contact with each other somewhat rapidly, which effect promotes oxidation of the surfaces due to the heat developed. The import of this action will be discussed later under Section IV.

Section III.—Metallographic Examination.

Since it appeared that the material which clung to the surface of the rolls and produced the depressions in the sheets was, undoubtedly, picked up from the sheets which had previously passed through the rolls, it was necessary closely to examine the streaks found on the sheets. Visual examination of the streaks under a binocular microscope revealed that the surface of the streaks was coated with scale and had a rough smeared appearance, as though the material had been plastic. Microsections were made of various areas in a number of the sheets. A transverse section through one of the raised streaks is shown in Fig. 3. From this it will be seen that a change in the structure of the material of the sheet is apparent near the streak and that the effect extends to the centre of the sheet.

Some sections showed a small cavity at the base of the streak, where the streak had started to break away from the parent material of the sheet.

By mounting a piece of a sheet, about 1 in. square, on a block of steel, it was possible to rub down the surface of the sheet. By further grinding and polishing a section of the sheet could be obtained in a parallel plane.

A very significant difference was seen in the structure of the streak and the general structure of the sheet. The grains composing the sheet itself were comparatively large and elongated, as illustrated in Fig. 4, whilst the grains in the streaks were much smaller, and equi-axed (Fig. 5). A section at right angles to the plane of the surface of the sheet, and in the direction of the streak, is shown in Fig. 6, in which these small equi-axed grains are seen more clearly. This dissimilarity of the grain size is in the author's opinion of vital significance.

Roll Structure.

The surfaces of various rolls were examined by taking a section at an exceedingly small angle to the surface. It could be detected that the pearlite and, in particular, the ferrite in the pearlite had undergone wear and been oxidised in preference to the cementite. The confusing effect of the damaged surface of the rolls makes it impossible to obtain a satisfactory photograph. A section at right

angles to the surface is illustrated in Fig. 7, where it will be seen that the structure is comparatively coarse.

Section IV.—Discussion and Conclusions.

The recrystallisation of the metal composing the streaks points to one thing, namely, that the temperature of these streaks must have exceeded the recrystallisation temperature of the material and, judging from the relatively small size and equi-axed shape of their crystals relative to those of the sheet, must have done so to a considerable degree.

The cause of this rise in temperature must be sought from a consideration of the rolling operations and the form of deformation of the sheet.

It is obvious that, in the passage of the stock through the rolls, the volume of material which enters the rolls must be practically equal to that which leaves them. It has been suggested, and evidence has been given for the assertion by Caswell[2] and others, that there is a simultaneous slipping back of the stock over the face of the rolls at the entry of the stock into the rolls and a forward slip on its exit from the rolls. In an area confined to the middle zone it is probable that no slip occurs, as was shown by Osborne Reynolds[3] in his experiments on rolling friction.

According to Caswell[2] the velocity V_0 of the stock at the exit is given by the equation :

$$V_0 = \frac{\omega r(T \cos \theta + t)}{2t}$$

where ω is the angular velocity of the rolls in radians per second.
r is the radius of the rolls in inches.
T is the thickness in inches of the stock before the pass.
t is the thickness in inches of the stock after the pass.
θ is the angle of the " bite " *in radians*.

In a more convenient form the equation for the velocity at exit is given by the following :

$$V_0 = \frac{\omega}{4t}[T(D - T) + t(T + D)] \times \frac{60}{12} \text{ ft. per min.}$$

where D is the diameter of the roll.

The slip at exit has a value $V_0 - \omega r$.

The slip, which occurs after the " no slip " section or zone of the " bite " takes place in the same direction as the movement of the stock and accelerates the movement produced by compression in the earlier parts of the " bite." Therefore the flow which occurs after the " no-slip " section has a character of extrusion as well as compression, so that the operation of rolling has been described as a process of compression and extrusion.

Now the slip on the roll face, either before or after the no-slip section, is produced by forces which can overcome, to some extent,

the frictional resistance on the roll face, and the actual speeds and slip of the stock, after a pass, will be largely controlled by the frictional resistance. If there is considerable friction, it is conceivable that roll-face slip will not occur under certain conditions, and then the constant volume flow between the rolls can only be maintained by the occurrence of internal slip in the material itself.

It may be mentioned here that the size of the rolls has an influence on the amount of slip, for the slip at exit is slightly greater with larger rolls than with small ones, because the zone of contact is greater for a large roll, and therefore the friction zone is larger. With all sizes of roll, as the stock admitted to the rolls decreases in thickness, the friction zone at entry exerts a greater effect on the internal mass of the material. With thick stock, the constraint of the roll friction on the material exerts its influence to a certain depth, and the zone of the material out of this sphere of influence is able to accommodate itself by internal slip to the stresses imposed. When, however, the stock is thin, the roll friction may be able to constrain the material to the full cross-section, and there will be less relative movement between the different parts of the stock, which will result in a greater tendency for uniform movement of the mass to occur towards the exit of the pass. It is therefore probable that a greater amount of slip over the roll face will occur with thinner material than with thick, because the energy stored up in the constrained friction zones is greater and is released after passing through the zone of no slip.

In the foregoing remarks it has been presumed that the surface of the roll has been of uniform character, and the coefficient of friction constant at every point on the surface. The structure of the surface of the rolls in practice, however, is duplex at least, if the two constituents cementite and pearlite only are considered. These two constituents are different in hardness and probably oxidise or scale at different rates. At the commencement of the week, when rolling operations begin, the surface will be comparatively uniform in character. When, however, after a short time of working, the relative slip between the two rolls increases in extent, as explained in Section II., the rate of wear and local scaling will be intensified, aided by the fact that the surfaces of the top and bottom roll make closer contact with each other over their length, as the rolls lose their camber on heating up. Local heating, by relative motion, can be quite intense, as has been demonstrated by Bowden and his collaborators,[4, 5] who found that when two metallic bodies are moved relatively to each other, although the mass of metal may remain cool, high temperatures of the order of 1000° C. may be developed locally at the surface of points of contact. The factors which control the temperature attained are principally the load, speed, and the coefficient of friction, thermal conductivity and softening or melting points of the metals rubbing together, whilst the relative hardness has little effect.

Considering now the effect of the varying character of the roll surface on the deformation of the sheets, it can be seen that, if at a particular local small area, or areas, on the surface of the roll, the coefficient of friction is lower than that of the surroundings, owing to a layer of scale or to a smoother area on the roll surface, the tendency for slipping at exit will be increased. The tendency for extrusion will be facilitated, and the material of the sheet at this point will move relatively rapidly in relation to the roll-face speed and the value $V_0 - \omega r$ increases to a higher value. This rapid extrusion of a small particle of the material may develop heat locally, sufficient to raise the temperature considerably—so much so, in fact, that a " tacky " stage of the material may be reached, which may be sufficient to cause the streak formed to adhere to the surface of the roll, and to be torn from the sheet. The comparatively rapid cooling of the streak by conduction from the high temperature when slipping ceases will facilitate the adhesion. The fact that the streak is elongated in the direction of rolling lends support to the theory that the direction of slip is in this direction. It must not be forgotten that the sheets from which particles have been torn out will exhibit the appearance of roll marks on their surfaces.

If, for any reason, the amount of deformation of the sheet is relatively greater at a particular part, the tendency for greater slip to occur is intensified over this area, because the material has to accommodate itself to allow the greater volume of material to pass through the rolls, with a corresponding increase in internal slip and stored-up strain in this zone. This tendency for greater slip on exit from the rolls will be manifested by a greater tendency for streaks to form if the surface of the roll is conducive to such a result. The increase in amount of deformation can be caused by the sheets being thicker in one part than another, due to the form of deformation which has previously taken place in the roughing roll. An instance of this is seen when the steel guides, which support the " iron " when it enters the rolls, have worn the roughing rolls to a slight extent where they bear on the surface of the rolls. The singles subsequently rolled in the finishing rolls are somewhat thicker at those areas corresponding to the hollowness in the roughing rolls. The frequency of the incidence of roll-marks at the one-third widths of the sheets can, possibly, be largely ascribed to this cause.

It is also conceivable that if the camber on the rolls is not uniform, and there is less " hollowness," or, in other words, more " pinch," at one particular area of the roll, the deformation of the pack will be greater at this part than at others and may be sufficient to give rise to local slipping to such an extent as to cause streaks to be produced.

It will be realised that the softer the steel the more readily will it be extruded, and this would appear to account for the greater

tendency of so-called " basic " steel (which is comparatively soft compared with so-called " acid " steel) to suffer from roll-marks.

If the layer of scale on a sheet is thick, the lubricating effect of this scale at the temperature of working is sufficient to blanket the differences in friction coefficients of the surface of the roll. This would explain why packs heated in a gas-fired furnace are more subject to roll-marks, since the thickness of scale formed on such packs is much thinner than that produced when a coal-fired furnace is employed.

In considering the possible ways of alleviating the trouble, it would seem that if the top rolls were driven the trouble would disappear. A somewhat more complicated drive is then necessary, but there are indications that this method is being adopted.

A closer texture of the rolls is another step which might mitigate the trouble. This would involve the use of alloy additions, such as nickel, to refine the structure.

It is essential that care be taken to ensure that the amount of deformation in the finishing rolls is uniform over the greater part of the width of the pack by paying close attention to the form of deformation taking place in the roughing as well as in the finishing rolls.

Acknowledgments.

The author wishes to express his thanks to Principal C. A. Edwards, D.Sc., F.R.S., and the authorities of the University College of Swansea for providing facilities to carry out some of the experimental work; to Messrs. Baldwins and the staff of King's Dock where a large proportion of the work was carried out; and to other works where experiments were conducted. To Mr. D. Luther Phillips, M.Sc., the author would like to express his especial thanks for suggesting the work and for much encouragement. Finally, the author would express his appreciation of the assistance given by Mr. L. H. Harold in some of the experimental work.

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THE INFLUENCE OF THE STEEL-BASE COMPOSITION ON THE RATE OF FORMATION OF HYDROGEN-SWELLS IN CANNED-FRUIT TINPLATE CONTAINERS.—PART I.*

By T. P. HOAR (Metallurgical Laboratories, Cambridge), T. N. MORRIS (Low-Temperature Research Station, Cambridge) and W. B. ADAM (Fruit and Vegetable Preservation Research Station, Chipping Campden).

(Fig. 1 = Plate IX.)

Synopsis.

The rate of formation of hydrogen-swells in packs of typical British canned fruits has been studied in relation to the composition of the steel base of the tinplate by means of statistically-planned canning experiments. A "random sample" of the tinplate at present on the British market has been used, and each can has been analysed for sulphur, phosphorus and copper after forming a hydrogen-swell in storage under defined conditions. The corrosion rate and corrosion potential of the steel base of each can, in citric acid, have also been measured. The results are correlated by the standard methods of statistical analysis.

The present paper gives results for packs of blackcurrants, white cherries, gooseberries, loganberries, Pershore plums, raspberries and strawberries in double-lacquered cans. It is shown that the rate of formation of hydrogen-swells is significantly correlated with the corrosion rate of the steel base in citric acid. For several fruits the rate of swell-formation is lowest when the steel base has a high (up to 0·2%) copper content, while for others it is lowest when the phosphorus content is lowest; in general, it is suggested that the use of high-copper (0·16–0·22%) low-phosphorus (0·03–0·045%) steel should roughly double the expected life of packs of these fruits, on the average.

Correlation between the composition variates themselves and the cathodic efficiency of the steel for hydrogen evolution have been discovered, and are discussed in relation to the rate of formation of hydrogen-swells.

I.—Introduction.

The storage of fruit in the "tin can" is a process that has achieved a wide and deserved degree of success. There is, however, an outstanding problem that has so far not been entirely overcome: The formation of so-called hydrogen-swells during storage. These "blown" or "domed" cans are caused by the evolution within the can of hydrogen formed by the corrosion of the tinplate by the fruit acids, and are unmarketable. Furthermore, a can that has

* Received June 14, 1939.

become domed sometimes suffers actual perforation not long afterwards. Although a great deal of canned fruit is so rapidly consumed that the problem does not arise, there are at least two important directions in which a reduction in the rate of formation of hydrogen-swells would be very desirable : (1) In assisting canners to " carry over " packs * from one fruit season to the next, when there is a glut, or to insure against a poor harvest in the next year; (2) in facilitating the export to hot climates of fruits that at present fail too rapidly to be a commercial proposition, owing to the increase of the corrosion rate with increase of temperature.

Previous researches have indicated that one important factor influencing the rate of tinplate corrosion and hydrogen formation is the composition of the steel base. The influence of composition on the rate of attack of steel by acid media has been much studied, especially by Bardenheuer and Thanheiser,[1] by Hoar and Havenhand [2] and by Edwards, Phillips and Thomas,[3] while the direct influence of the steel-base composition and/or corrosion behaviour on the rate of formation of hydrogen-swells in canned fruit has been investigated by an American committee representing canning and other interests,[4] by McConkie,[5] by Hirst and Adam,[6] by Morris,[7] by Vaurio, Clark and Lueck [8] and by Rhodes.[9] These various researches will be referred to in detail later.

The present work is primarily an investigation of the influence of the sulphur, phosphorus and copper contents of the steel base on the rate of formation of hydrogen-swells in a representative selection of British fruits. Two methods of approach are possible : (1) " Synthetic " steels and tinplates, containing various known contents of sulphur, phosphorus and copper, may be manufactured, made into cans, and tested with the various fruits; (2) a " random sample " of commercial tinplate may be taken, made into cans, and similarly tested; every can is analysed, after it has given a hydrogen-swell, for sulphur, phosphorus and copper, and the results are interpreted by statistical methods. Such a " random sample " *need not be very large*, for precise methods are available for interpreting results from small samples of from 20 individuals upwards; and such results may be extrapolated to the large population from which the small sample was drawn *with a degree of certainty that can be calculated mathematically* (*see* section III. (3)).

The statistical method has been utilised in this research for the following reasons :

(1) It is desirable from every point of view to discover the most favourable steel composition that is produced in present practice before embarking on a search for material even better. The statistical method ensures that the field of present-day commercial material is fully explored but not exceeded.

* This term is frequently used throughout the paper, and indicates the canner's " pack," *i.e.*, a number of cans filled with the same fruit. It must not be confused with the steel-mills' " pack " of sheets.

(2) In the " synthetic " method, comparisons between synthetic steels differing in one variable only, the others being held constant, are required. This involves a dilemma: Either large " practical " heats and ingots are made (at great expense), and reproducibility is almost impossible; or small, reproducible laboratory preparations are made, and analogy to " practical " material is partially lost. The statistical method avoids these difficulties, and indeed requires only a *comparatively small* " random sample " of the practical population that it is desired to investigate.

The " population " chosen for this first study was tinplate as it at present reaches the British market, that is, tinplate made almost exclusively from hot-pack-rolled British dead-mild steel.* All the present results refer *solely* to this type of material, which is found, however, to give a wide range of variation of sulphur, phosphorus and copper contents, and also considerable variation of the rate of formation of hydrogen-swells in fruit packs.

The general plan of the work was as follows: A suitable random sample of 29 cases of tinplate was obtained by the International Tin Research and Development Council, and each case was made up into a seperate batch of cans under industrial conditions. Two cans from each batch were packed with fruit under standard conditions at the Fruit and Vegetable Preservation Research Station, Chipping Campden; the packs were stored there at 35° C.,† each can being examined every week for " doming." As soon as this (or, in one or two cases, perforation) occurred, the can was removed and emptied. It was analysed for sulphur, phosphorus and copper at the Metallurgical Laboratories, University of Cambridge, and corrosion tests of the steel base were made at the Low-Temperature Research Station, University of Cambridge. Finally the data were reduced by the usual statistical methods.

In this paper, results for blackcurrants, sweet white cherries, gooseberries, loganberries, yellow Pershore plums, raspberries and strawberries in double-lacquered cans are given; further results will be reported later. As well as the correlation of the rate of formation of hydrogen-swells with the steel-base composition, correlations have been made with the corrosion rate of the steel base in citric acid under laboratory conditions, and the electrochemical relationships previously described[(2)] have been further clarified.

* Strip plate from the new Ebbw Vale mills was not, of course, available when this work was planned: further experiments will be necessary to compare the new material with the older type.

† This temperature had previously been adopted at Campden, for it imitates the tropical conditions under which cans fail rapidly, and provides a legitimate degree of acceleration of the tests, as compared with the rate of formation of hydrogen-swells at ordinary " temperate " temperatures.

II.—Experimental Techniques.

(1) *Source of Tinplates.*

Through the kindness of Mr. W. E. Hoare, of the International Tin Research and Development Council, 29 cases of tinplate (95–100 lb. substance; $1\frac{1}{2}$ lb. (nominal) tin per basis box) were obtained as a random sample of such tinplate as it at present reaches the British market. Of these, 17 cases came from 16 different factories, 5 cases (all different sources) *via* an agent, 4 cases from a consumer, 2 cases from a different consumer, while 1 case was of unknown origin; so that a very fair randomisation of the sample was achieved. One case was of French and 2 cases were of Italian origin; these had compositions within the large range found in the British tinplates, and showed no unusual features; they were therefore included in the sample.

(2) *Manufacture of Cans.*

Can manufacture was very kindly undertaken by The Metal Box Co., Ltd., at their Acton works. Each case of tinplate was made up into No. *A*2 cans, $3\frac{7}{16}$ in. in dia. by $4\frac{1}{2}$ in. high, after most of the sheets had received a double coating of lacquer applied by the company's usual processes.* Can bodies and ends were perforce made from different sheets, as any attempt to make body and ends for each can from the same sheet would have been technically difficult, and would indeed have introduced undesired departures from industrial practice. Differences between sheets, and thus between the body and end of any individual can, have been partially compensated for in the chemical analyses; the analytical sample represents a weighted mean of the two parts (*see* section II. (4)).

(3) *Packing and Storage of Fruit.*

Blackcurrants, sweet white cherries, gooseberries, loganberries, yellow Pershore plums, raspberries and strawberries were packed at the appropriate seasons. The variety of each fruit chosen was that most commonly used by canners. The state of ripeness was also usual except in the case of cherries, which were packed at a slightly riper state than is usual in order to ensure the low hydrogen-ion concentration thought, on the evidence of previous work, to promote rapid failure in this fruit. Two cans and ends were taken at random from each batch for filling with each fruit. The cans, on removal from the cartons, were coded externally and then distributed at random on a large filling table. To minimise any error from variation in composition of the fruit contained in different chip baskets, the filling was gradual over the whole batch of cans;

* The remaining sheets were made into plain cans; results given by these will be reported later.

individual cans were not filled from the same chip basket. The contents were finally adjusted to a standard weight. Syrup containing 45% by weight of cane sugar was added at a temperature of 75° C.; a metal displacement "topper" was then inserted to give a standard headspace of 35 ml. in the sealed cans, and the ends were then clinched on lightly, so as to avoid chilling of the surface of the contents before the final sealing. The cans were exhausted for 6 min. in water at 85° C., sealed, and processed at 100° C. for times appropriate to each fruit. After cooling in water to about 35° C. and drying-off in air, the cans were placed in a constant-temperature room at 35° C. (± 1° C.) and thereafter examined weekly. For examination, each can was tilted slightly and tapped on the bottom seam to permit the ends to dome when they had reached a state of unstable equilibrium. Domed cans were removed, emptied, washed and dried, and sent to Cambridge for analysis and corrosion tests. Subsidiary experiments showed that the excess internal pressure required to produce doming was 28·8 cm. of mercury, with a probable error of ± 2·0 cm.

Three additional cans were packed with each fruit and stored at room temperature for one month; after this period the oxygen initially in the headspace has generally disappeared, and the maximum internal vacuum is reached. At this stage the vacuum and headspace were measured, and the hydrogen-ion concentration and total acidity of the contents were determined. The mean results are given in Table I.

TABLE I.—*Particulars of Can Contents.*

Fruit.	Headspace. Ml.	Vacuum. Cm. Hg.	*p*H (by Quinhydrone Electrode).*	Acidity (Citric Acid).† %.
Blackcurrants . .	45	31	3·31	1·12
White cherries . .	47·5	30	4·40	0·12
Gooseberries . . .	39	33	2·89	1·12
Loganberries . . .	46	30	2·92	1·17
Plums (yellow Pershore) .	46·5	31	3·03	0·84
Raspberries . . .	41	28	3·58	0·39
Strawberries . . .	52	26	2·99	1·16

* Since these measurements were made, Blair [10] has shown that the quinhydrone electrode leads to values of *p*H about 0·1 unit too high in canned tomatoes, citrus fruits and cherries, owing to the reducing nature of the solution. Thus the present figures are doubtless a little high for cherries, and probably for gooseberries, but not for the red fruits containing oxidising anthocyanins.

† Obtained by titrating to an end-point of *p*H 7·0 with sodium hydroxide.

The increase in headspace from the initial 35 ml. given by the displacement topper is due to a small extent (about 2–4 ml.) to contraction of the contents by cooling, but is mainly caused by displacement of the internal gases in the fruit during processing and by the partial vacuum later produced in the can.

The rate of loss by hydrogen-swell formation, for the packs of blackcurrants, gooseberries, loganberries, raspberries and strawberries was somewhat greater than is usual for these fruits at 35° C., while the first loss in each case was also at an earlier date than usual. The cans of cherries and yellow Pershore plums, however, formed hydrogen-swells a little less rapidly than usual. Table II. shows the rate of loss of each pack in these tests compared with the average of six standard tests (at 35° C.) made on ordinary cans on previous occasions at Campden; the only difference in procedure in the earlier tests was that the lids were not clinched before exhausting.

TABLE II.—*Rate of Formation of Hydrogen-swells.*

Cans stored at 35° C.

Fruit.	Test.	Time, Weeks, to Reach Loss of—		
		15%.	25%.	50%.
Blackcurrants	This test	14	16	21
	Previous average	16	18	29
White cherries	This test	20	22	25
	Previous average	17	18	21
Gooseberries	This test	21	23	29
	Previous average	38	44	58
Loganberries	This test	18	20	23
	Previous average	22	25	32
Yellow Pershore plums	This test	25	30	37
	Previous average	18	24	31
Raspberries	This test	15	17	20
	Previous average	21	23	32
Strawberries	This test	13	14	19
	Previous average	21	24	28

As individual samples of each fruit vary considerably in their corrosive action, the differences recorded are probably not significant with respect to other variates. The faster losses recorded with strawberries and raspberries may, however, be attributed to a definite cause; the sugar used in each case contained about 25 parts per million of sulphur dioxide (giving a final content of 4–5 parts per million in the canned products). However, 70 parts per million of sulphur dioxide in the sugar is permissible by law, and although high sulphur-dioxide contents are doubtless undesirable, such amounts as 25 parts per million are occasionally found in practice. The sugar used in all the other tests was virtually free from sulphur dioxide.

(4) *Sampling of Cans.*

For the chemical analyses, a strip 10 × 5 cm. was cut from the body of the can, and a strip 6 × 4 cm. from the bottom end. These

were delacquered in a hot solution of sodium disilicate (water-glass). They were then washed, and detinned in a cold solution of antimony chloride in hydrochloric acid; the black deposit of antimony was swabbed off under the tap, and the small amount of remaining tin-iron compound removed by a few seconds' dip in cold 1 : 1 nitric acid; finally they were rinsed, soaked in dilute caustic soda solution for a few minutes to remove any occluded acids, washed and dried. The larger strip was then cut into 5 strips 10 × 1 cm., and these were further cut into 25 pieces approximately 2 × 1 cm.; the smaller strip was cut into 24 pieces 1 × 1 cm. In any analysis, equal numbers of the larger and smaller pieces were taken at random, so that the analysis should represent a weighted mean of that of the body and bottom end of the can, with the body analysis preponderating by 2 : 1. This scheme was adopted owing to the known tendency for corrosion to be greatest at the can seams, *especially the body side seam*; it is an attempt to take the most representative sample of the can as a whole, bearing in mind the usual location of the greatest attack. For sulphur and copper analyses, 7 body pieces and 7 bottom-end pieces, giving 4–5 g., were used; for phosphorus, 4 pieces of each kind were further subdivided diagonally, half of each piece being taken, giving 1·3–1·5 g.

For the corrosion tests, only the body of the can was suitably flat, and indeed most of the bottom end was required for the chemical analyses; a strip 10 × 6 cm. was cut, delacquered and detinned as in the previous case, except that the small amount of compound left after the antimony-chloride treatment was removed by abrasion with emery-cloth in a standard manner. Specimens 7·5 × 2·5 cm. and 6·5 × 2·5 cm. were prepared from this strip for the two types of corrosion test (*see* sub-section (6)).

(5) *Chemical Analyses.*

(1) *Sulphur* was determined by the evolution method, slightly modified to allow greater rapidity and accuracy, as described by Hoar and Eyles.[11]

(2) *Phosphorus* was determined by the molybdenum-blue method, as applied to steel analysis by Hoar;[12] details will be found in the original paper.

(3) *Copper* was determined by the diethyldithiocarbamate method, previously described by Hoar,[13, 14] with a slight modification; larger titres of the copper-bearing solution were used, to permit the use of photo-electric colorimetry. The colour due to ferric iron was allowed for by estimating it in a visual colorimeter, as explained in the original paper.

All the analyses were carried out by the same two operators, each confining himself to particular operations. In this way chance errors were minimised, and any systematic error was equalised for all the determinations. It is thought that any one sample analysis

is certainly correct to within $\pm 3\%$ of its value; it is recognised also that the difference between duplicate analyses of any one can would often be of a similar order of magnitude, owing to sampling variations. Whenever an unusual figure was found, it was checked, and such duplicates agreed well within the stated limits.

(6) *Corrosion Tests.*

The corrosion tests on the detinned specimens of steel were carried out :

(*a*) Under closed conditions in the presence of a limited amount of air, and

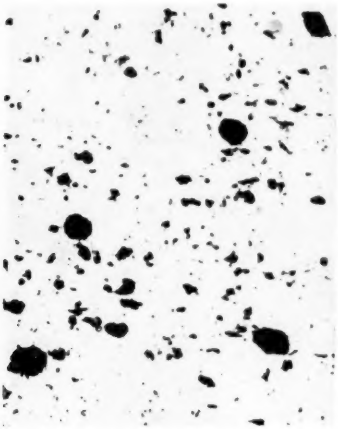
(*b*) In open beakers.

For the former tests, the technique of Morris and Bryan [15] was used. The $7{\cdot}5 \times 2{\cdot}5$-cm. specimens were abraded with *FF* emery-cloth, degreased with benzene and alcohol and weighed. Each strip was then placed in a wide-mouthed bottle, resting against the side in a sloping position, and covered with 220 ml. of 0·5% citric acid, this amount being sufficient to leave a headspace of approximately 10 ml. after the closing of the bottle with a perforated rubber bung fitted with capillary tubing. The bottles were placed in a water thermostat at $25{\cdot}0 \pm 0{\cdot}1°$ C. and connected to gas burettes. After 72 hr. the specimens were taken out, rinsed in boiling water and absolute alcohol, dried in a desiccator and weighed.

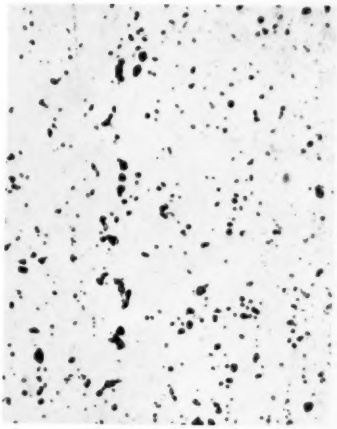
The technique of Hoar and Havenhand [2] was used for determining the corrosion weight-loss under " open " conditions and also the corrosion potentials of the specimens. The $6{\cdot}5 \times 2{\cdot}5$-cm. specimens were abraded with *FF* emery-cloth and degreased twice with carbon tetrachloride. After being weighed, they were covered with paraffin wax for a length of 3·0 cm. from the top, leaving $3{\cdot}5 \times 2{\cdot}5$ cm. of the metal exposed. They were then clipped to metal holders, which were fixed to 270-ml. beakers, 11 cm. high by 6 cm. in dia., with soft red wax. 0·1*M* citric acid (about 2%) at 25° C. was then run into the beakers until the top of the exposed part of the specimen was 1 cm. below the liquid-line; this gave a total volume of 200 ml. The beakers and contents, 36 in each run, were then placed in a metal box fitted with a rigid wooden base and a hinged lid. The whole was contained in a thermostat room at a mean temperature of $25{\cdot}0 \pm 0{\cdot}1°$ C., the fluctuations of temperature inside the box being less than 0·05° C. After 72 hr., the electrode potential of each specimen was measured, by means of a valve electrometer, against a standardised quinhydrone half-cell containing quinhydrone in 0·1*M* citric acid. The specimens were then removed, washed, dried, dewaxed, degreased and weighed.

(*a*) Massive Cementite at Grain Boundaries.

(*b*) Pearlitic Areas Bounded by Coagulated Cementite.



(*c*) Cementite within Ferrite Grains.



(*d*) Finely Divided Cementite within Ferrite Grains.

(*a*) and (*b*) are typical of all batches of tinplate here reported. (*c*) and (*d*) were found in one batch not included in the present results.

FIG. 1.—Distribution of Cementite. Polished with magnesia, lightly etched in 2% alcoholic nitric acid, lightly repolished and stained in sodium picrate. × 750.

[*Hoar, Morris & Adam.*

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III.—Experimental Results and Statistical Analysis.

(1) *Numerical and Micrographic Results.*

The numerical results of storage, chemical analysis, and corrosion tests of packs of blackcurrants, cherries, gooseberries, loganberries, Pershore plums, raspberries and strawberries in double-lacquered cans are given in Tables III. to IX. In these Tables the following symbols are used :

T = Time of formation of hydrogen-swell at 35° C. (weeks).
S = Sulphur, P = Phosphorus, Cu = Copper } content of steel base (parts per 100,000 *; *i.e.*, 66 = 0·066%).
M = Weight-loss of corrosion specimen 7·5 × 2·5 cm. under "closed" conditions (mg. per 72 hr.).
H = Weight-loss of corrosion specimen 3·5 × 2·5 cm. under "open" conditions (mg. per 72 hr.).
E = Corrosion potential of corrosion specimen under "open" conditions (mv., against hydrogen electrode in 0·1M citric acid; add −117 mv. for normal hydrogen scale).
ΔE = "Cathodic increment" of corrosion specimen under "open" conditions (mv.).

It will be noted that "duplicate" cans, made from the same case of tinplate, often had widely different compositions. This is doubtless due to segregation in the ingot, and occasionally to the presence of sheets from different ingots in the same case; it is advantageous rather than otherwise, as it leads to a larger apparent size of the tinplate sample (*see* sub-section (3)).

Micrographic examination of sections of a number of cans showed no unusual results except in one case noted below. Typical photomicrographs of cementite distribution are shown in Fig. 1, (*a*) and (*b*); both massive cementite between the ferrite grains and small patches of coarse pearlite bounded by coagulated cementite at the edges occurred in all the batches of tinplate here reported.

One batch of cans gave highly anomalous results, failure through hydrogen-swells occurring abnormally early even with the slow-failing unlacquered packs that will be dealt with in a later paper. The steel base of these cans frequently had a cementite distribution, shown in Fig. 1, (*c*) and (*d*), not found in all the other batches. In view of this different structure, which is doubtless due to annealing differences, and the influence of which on corrosion is being further investigated, the batch is not included in the results here reported.

(2) *Mean Composition of Tinplate Sample.*

In order to define, in point of composition, the population of tinplate from which the present sample was drawn, and to which

* For convenience in printing.

TABLE III.—*Blackcurrants.*

No.	Storage. *T.*	Analysis.			Corrosion.			
		S.	P.	Cu.	*M.*	*H.*	*E.*	$\Delta E.$
1	23	66	59	98	149	102	−203	+ 2
	34	47	41	108	151	131	−207	+ 3
2	21	73	62	96	165	156	−213	0
	25	50	48	83	195	181	−215	+ 1
3	18	82	62	85	196	181	−213	+ 3
	22	89	55	83	143	135	−211	− 1
4	11	110	79	59	232	287	−220	+ 5
	14	116	88	59	200	162	−219	− 5
5	20	60	36	130	133	89	−206	− 5
	26	58	36	121	68	48	−189	− 4
6	17	75	67	139	144	88	−198	+ 3
	32	67	46	194	107	51	−176	+11
7	24	55	34	124	132	88	−198	+ 3
	34	39	27	182	110	57	−187	+ 3
8	13	42	45	73	211	187	−216	+ 1
	18	43	48	78	211	190	−211	− 6
10	27	54	65	118	153	81	−189	+10
	33	46	47	110	117	60	−190	+ 2
11	13	92	75	75	231	253	−223	0
	27	69	67	75	219	284	−227	− 2
12	14	56	70	70	257	391	−215	+17
	23	46	65	51	191	137	−204	+ 7
13	14	70	92	67	243	316	−217	+10
	24	79	67	111	181	226	−224	− 3
14	15	78	73	83	219	284	−219	+ 6
	21	59	60	76	200	221	−219	+ 1
15	17	55	59	49	230	231	−215	+ 6
	17	54	60	52	224	240	−218	+ 4
16	24	64	42	93	126	62	−203	−10
	27	61	42	93	76	59	−191	0
17	16	84	72	83	202	195	−213	+ 5
	17	78	59	79	212	207	−216	+ 3
18	21	66	42	99	98	71	−194	+ 2
	24	66	48	269	90	53	−193	− 5
19	22	60	51	207	160	146	−210	+ 2
	26	42	19	196	52	33	−165	− 2
20	18	57	57	80	204	202	−211	+ 7
	23	56	56	75	202	110	−209	− 3
21	20	61	61	83	224	203	−213	+ 5
	26	44	45	72	171	116	−211	− 3
22	14	72	78	65	251	396	−217	+15
	21	76	56	87	206	200	−220	− 2
23	13	79	75	86	205	254	−219	+ 4
	22	81	65	91	204	188	−217	0
24	15	109	112	99	234	239	−214	+ 8
	16	82	83	82	225	226	−214	+ 7
25	16	78	74	82	138	95	−199	+ 4
	23	85	72	80	109	85	−203	− 3
26	23	88	73	89	211	173	−217	− 2
	23	74	69	81	189	158	−209	+ 4
29	18	38	20	82	124	43	−167	+13
	23	42	39	80	82	44	−171	+10
31	14	31	29	23	250	262	−228	− 4
	17	24	26	26	236	184	−221	− 4
32	27	44	19	234	80	51	−183	+ 4
	28	44	18	244	97	50	−175	+12

TABLE IV.—*Sweet White Cherries.*

No.	Storage. *T.*	Analysis.			Corrosion.			
		S.	P.	Cu.	*M.*	*H.*	*E.*	ΔE.
1	22	62	62	97	200	210	−220	− 1
	37	52	42	131	157	93	−203	− 1
2	29	65	59	97	172	135	−211	− 1
	36	60	58	101	150	91	−205	− 3
3	20	73	55	98	204	191	−209	+ 8
	26	88	58	87	115	55	−189	0
4	25	71	64	61	200	259	−226	− 3
	30	76	68	51	217	262	−222	+ 2
5	24	59	41	127	116	93	−201	+ 1
	24	60	39	129	103	76	−198	0
6	22	69	52	201	78	54	−190	− 1
	26	49	40	139	86	45	−181	+ 1
7	22	39	25	154	102	52	−184	+ 4
	29	61	40	182	90	58	−194	− 3
8	19	50	52	76	236	182	−211	+ 5
	24	40	46	55	231	225	−221	− 1
10	26	51	42	114	158	102	−206	− 1
	33	45	43	104	130	71	−191	+ 5
11	17	80	69	72	237	334	−219	+ 9
	37	78	67	85	217	207	−221	− 2
12	18	63	86	50	218	307	−213	+14
	22	61	54	95	166	139	−211	0
13	20	52	68	86	232	261	−213	+10
	26	68	59	109	94	59	−194	− 2
14	22	77	67	110	200	140	−213	− 2
	22	58	61	72	243	214	−220	0
15	21	60	57	53	197	245	−221	+ 1
	24	50	52	48	130	135	−213	− 3
16	28	60	41	93	190	149	−218	− 6
	33	65	44	99	93	56	−191	− 1
17	22	64	52	94	208	179	−217	− 1
	29	85	61	71	218	253	−225	− 2
18	26	66	52	149	169	135	−212	− 2
	29	64	42	132	147	87	−200	+ 1
19	37	38	30	147	114	76	−195	+ 3
	43	33	13	225	53	32	−164	− 5
20	22	54	55	76	220	213	−218	+ 1
	27	56	54	64	190	169	−221	− 6
21	24	46	46	69	181	192	−212	− 5
	39	50	57	66	104	95	−209	− 6
22	20	56	61	72	163	92	−191	+11
	22	67	79	75	247	379	−221	+10
23	26	63	75	81	230	263	−224	0
	26	84	76	80	245	329	−228	0
24	25	82	76	92	210	172	−214	+ 1
	26	74	69	78	197	218	−222	− 2
25	27	74	73	75	162	155	−213	0
	29	66	67	85	214	228	−221	0
26	28	84	76	82	232	265	−222	− 2
	28	80	79	82	176	185	−215	+ 2
29	17	45	81	45	299	445	−214	+20
	22	40	17	141	73	38	−158	+15
31	17	25	25	32	236	187	−206	+11
	25	27	25	37	213	156	−214	− 1
32	26	48	20	230	121	64	−197	− 4
	27	45	20	228	92	53	−191	− 3

Table V.—*Gooseberries.*

No.	Storage. *T.*	Analysis.			Corrosion.			
		S.	P.	Cu.	*M.*	*H.*	*E.*	ΔE.
1	37	48	44	100	157	133	−214	− 4
	37	65	65	104	193	187	−215	+ 2
2	21	74	70	99	198	199	−211	+ 7
	31	56	52	91	177	148	−213	− 1
3	24	89	58	81	213	194	−217	0
	40	84	53	88	87	63	−194	− 1
4	17	71	61	63	209	223	−221	− 1
	29	75	58	58	229	319	−227	0
5	31	63	34	131	70	54	−192	− 3
	39	46	34	132	91	66	−193	+ 1
6	12	85	70	155	125	70	−193	+ 3
	37	66	47	201	79	41	−185	− 8
7	33	56	38	193	94	55	−189	+ 1
	45	57	28	163	67	34	−174	−10
8	23	52	54	105	138	138	−207	+ 4
	23	53	56	102	151	134	−203	+ 7
10	37	56	47	117	116	67	−194	+ 1
	56	50	37	113	108	60	−189	+ 3
11	42	40	41	84	86	63	−193	0
	44	80	68	80	224	282	−229	− 4
12	20	54	81	72	273	433	−212	+22
	23	62	61	90	182	139	−212	− 1
13	31	64	64	78	226	231	−221	0
	36	64	61	82	212	152	−210	+ 3
14	23	74	65	99	199	217	−219	+ 1
	28	82	66	90	181	171	−219	− 4
15	25	51	49	50	241	281	−226	− 1
	25	52	40	47	187	211	−220	− 1
16	47	62	38	98	67	40	−182	− 6
	50	59	36	97	87	45	−188	− 6
17	16	82	63	75	230	248	−221	+ 1
	29	64	50	71	195	187	−219	− 2
18	37	66	39	138	120	76	−200	− 2
	37	59	55	127	144	95	−205	− 2
19	50	54	43	154	79	42	−176	+ 3
	74	45	22	189	54	42	−189	−10
20	16	48	57	70	213	196	−214	+ 4
	33	49	45	61	186	210	−223	− 4
21	28	61	68	60	190	208	−224	− 5
	32	45	48	66	149	100	−205	− 1
22	34	79	56	89	183	148	−215	− 3
	45	59	49	121	62	38	−170	+ 2
23	17	86	76	93	159	126	−205	+ 4
	17	96	72	82	210	209	−217	+ 2
24	23	79	70	95	206	188	−215	+ 2
	26	81	77	84	183	154	−211	+ 2
25	26	65	65	79	165	127	−206	+ 3
	26	77	70	82	129	110	−205	+ 1
26	26	79	78	93	201	174	−216	− 1
	31	76	65	84	199	214	−221	− 2
29	21	32	17	91	63	39	−165	+10
	23	27	10	87	150	84	−199	+ 1
31	20	25	24	31	235	205	−220	− 1
	23	32	31	30	230	255	−227	− 4
32	42	44	20	253	114	67	−196	− 1
	45	46	22	222	84	40	−179	− 3

TABLE VI.—*Loganberries.*

No.	Storage. *T.*	Analysis.			Corrosion.			
		S.	P.	Cu.	*M.*	*H.*	*E.*	$\Delta E.$
1	25	35	38	94	176	142	−212	− 1
	33	53	32	102	181	125	−203	+ 6
2	20	59	56	103	193	182	−217	− 1
	24	67	59	95	166	127	−211	− 2
3	25	83	54	89	79	59	−194	− 2
	32	73	38	82	200	165	−214	0
4	17	76	67	63	191	198	−217	+ 1
	18	70	64	55	219	235	−216	+ 5
5	20	61	35	130	128	68	−194	+ 1
	24	61	37	128	132	83	−207	− 7
6	27	63	44	200	88	51	−189	− 2
	27	76	61	159	131	62	−191	+ 2
7	25	62	43	150	123	88	−206	− 5
	36	48	48	184	65	51	−189	− 2
8	23	36	44	54	229	211	−219	0
	23	59	53	125	186	108	−203	+ 3
10	15	55	65	133	172	146	−199	+13
	27	55	42	114	158	91	−198	+ 4
11	20	79	74	73	254	330	−221	+ 7
	25	90	85	58	232	257	−226	− 3
12	21	72	56	114	187	191	−220	− 3
	25	51	44	64	64	53	−196	− 8
13	20	72	80	83	226	247	−215	+ 7
	23	55	56	97	232	259	−215	+ 8
14	19	72	61	107	159	176	−208	+ 8
	21	77	67	111	215	208	−217	+ 2
15	23	51	53	51	222	188	−218	− 1
	27	44	49	50	228	214	−221	− 1
16	23	52	36	98	179	102	−202	+ 3
	31	68	43	110	84	47	−190	− 6
17	20	64	65	67	246	366	−225	+ 5
	23	66	61	43	241	298	−225	+ 1
18	22	64	55	119	229	238	−218	+ 4
	24	58	52	114	214	228	−222	− 1
19	31	35	54	140	119	59	−181	+10
	39	45	24	208	68	47	−188	− 4
20	23	58	56	82	218	177	−213	+ 3
	25	51	55	66	202	244	−222	0
21	24	60	61	67	217	285	−227	− 2
	25	46	54	66	200	183	−221	− 5
22	21	88	77	105	206	188	−217	0
	27	80	62	92	213	200	−221	− 3
23	19	76	78	82	139	149	−202	+10
	21	93	78	96	154	139	−210	+ 1
24	22	69	59	87	213	181	−212	+ 4
	24	90	76	79	139	119	−212	− 4
25	23	80	81	81	132	93	−198	+ 4
	25	46	53	70	219	192	−217	0
26	20	83	75	84	231	279	−221	+ 4
	22	87	73	86	210	218	−218	+ 2
29	17	33	15	87	92	51	−185	+ 2
	18	41	23	84	119	45	−169	+13
31	13	25	31	18	256	295	−230	− 4
	14	34	26	19	267	313	−229	− 2
32	35	45	18	248	110	48	−181	+ 4
	39	44	16	248	98	67	−195	0

TABLE VII.—*Yellow Pershore Plums.*

No.	Storage. *T.*	Analysis.			Corrosion.			
		S.	P.	Cu.	*M.*	*H.*	*E.*	$\Delta E.$
1	30	57	55	109	166	124	−209	0
	52	52	52	98	156	156	−213	0
2	25	66	52	101	159	112	−205	+ 2
	52	62	57	98	148	126	−210	− 1
3	63	85	54	86	80	60	−194	− 2
	75	85	55	87	73	49	−190	− 4
4	33	72	64	51	180	154	−213	0
	36	74	66	59	178	101	−206	− 2
5	25	58	37	135	143	78	−202	− 4
	68	60	41	130	60	46	−189	− 6
6	39	65	45	205	49	32	−165	− 7
	62	76	38	210	87	38	−183	−10
7	37	52	33	210	76	37	−177	− 6
	55	48	25	174	61	44	−184	− 3
8	34	54	55	81	171	223	−223	− 3
	72	57	56	103	85	55	−186	+ 4
10	19	65	82	144	178	144	−206	+ 6
	37	59	71	94	176	131	−206	+ 4
11	22	79	74	88	248	379	−227	+ 4
	55	64	62	87	220	251	−224	− 1
12	22	55	92	49	260	402	−220	+12
	37	54	89	51	254	255	−215	+ 8
13	28	67	62	94	213	263	−227	− 3
	29	61	60	90	202	234	−218	+ 3
14	37	78	76	80	159	86	−203	− 2
	38	63	54	115	80	41	−177	0
15	48	47	50	48	189	200	−221	− 3
	50	58	58	50	222	202	−219	− 1
16	30	61	40	106	109	66	−197	− 3
	72	65	41	97	78	49	−187	− 3
17	22	60	61	55	241	334	−227	+ 1
	35	66	49	122	105	101	−209	− 5
18	55	70	38	146	108	70	−195	+ 1
	65	66	36	142	100	64	−196	− 2
19	37	41	25	221	47	28	−164	−13
	61	44	16	207	34	28	−160	− 9
20	29	57	59	88	214	217	−218	+ 2
	64	50	51	76	221	182	−216	0
21	51	58	61	72	179	201	−213	+ 5
	65	45	43	80	207	145	−206	+ 6
22	34	71	64	97	190	240	−220	+ 2
	46	76	69	105	119	66	−187	+ 7
23	23	90	82	86	228	295	−221	+ 5
	23	87	73	93	209	230	−220	+ 1
24	36	87	77	100	157	84	−198	+ 2
	54	47	46	94	184	178	−213	+ 3
25	44	76	67	84	71	56	−186	+ 4
	59	78	73	76	92	58	−190	+ 1
26	39	91	73	90	137	82	−205	− 5
	50	84	71	90	194	148	−209	+ 3
29	34	36	28	89	91	54	−181	+ 8
	37	36	32	79	80	38	−169	+ 3
31	28	28	27	23	238	310	−235	− 8
	37	28	25	26	177	88	−193	+ 8
32	66	44	21	238	69	46	−183	0
	67	31	19	237	135	58	−189	+ 2

TABLE VIII.—*Raspberries.*

No.	Storage. *T.*	Analysis.			Corrosion.			
		S.	P.	Cu.	*M.*	*H.*	*E.*	ΔE.
1	25	53	38	139	88	50	−179	+ 8
	29	64	60	102	193	147	−207	+ 5
2	14	63	60	92	141	122	−205	+ 3
	34	52	35	148	85	47	−179	+ 5
3	20	56	51	84	78	64	−198	− 4
	24	75	58	78	179	91	−201	+ 1
4	16	77	73	50	220	248	−224	− 2
	18	70	63	55	121	83	−201	− 1
5	23	58	39	133	84	56	−195	− 5
	27	59	39	127	89	54	−195	− 6
6	25	56	38	190	53	34	−179	−15
	31	62	37	191	71	40	−183	− 7
7	20	48	27	146	64	43	−188	− 8
	21	48	30	123	104	59	−194	− 2
8	18	41	50	52	201	148	−210	+ 2
	20	45	44	65	123	103	−206	− 1
10	19	68	81	131	155	67	−188	+ 7
	20	56	42	110	77	64	−193	+ 1
11	13	88	66	84	223	220	−224	− 4
	15	79	71	89	252	433	−229	+ 5
12	18	61	68	89	136	90	−201	+ 1
	19	53	83	44	167	150	−210	+ 2
13	14	87	79	118	168	161	−216	− 2
	15	80	66	116	166	128	−213	− 4
14	18	63	58	109	67	60	−185	+ 7
	20	70	66	98	141	100	−202	− 1
15	17	51	54	46	189	149	−210	+ 2
	19	54	57	48	145	117	−201	+ 7
16	30	61	40	95	168	110	−201	+ 5
	31	51	33	91	98	55	−183	+ 6
17	20	85	64	54	222	352	−230	− 1
	20	68	63	49	214	271	−226	− 2
18	19	55	47	93	183	143	−207	+ 5
	20	59	52	121	180	131	−210	0
19	20	38	33	153	143	96	−202	+ 1
	30	55	20	228	72	38	−179	− 6
20	17	55	61	64	126	130	−209	+ 2
	22	60	56	79	185	112	−209	− 2
21	15	56	60	71	162	151	−213	0
	20	56	61	63	165	144	−213	− 1
22	20	80	62	78	247	249	−227	− 4
	21	73	66	104	154	130	−209	+ 1
23	21	70	58	100	130	115	−206	+ 1
	29	84	64	107	175	97	−197	+ 6
24	18	51	49	80	207	180	−215	+ 1
	20	76	69	97	180	152	−213	0
25	16	86	79	79	119	80	−201	− 2
	29	71	64	78	170	142	−207	+ 4
26	25	71	69	76	177	171	−211	+ 4
	30	77	74	86	175	153	−211	+ 2
29	15	36	36	82	86	46	−173	+10
	20	22	55	10	306	428	−205	+29
31	12	30	25	22	239	164	−218	− 4
	13	26	31	25	261	199	−224	− 6
32	30	46	19	234	66	41	−169	+ 8
	31	46	20	237	94	54	−181	+ 8

TABLE IX.—*Strawberries.*

No.	Storage. *T.*	Analysis.			Corrosion.			
		S.	P.	Cu.	*M.*	*H.*	*E.*	ΔE.
1	29	45	44	88	176	104	−201	+ 4
	29	36	30	111	137	79	−195	+ 4
2	15	49	35	126	61	43	−177	+ 3
	17	60	51	119	121	95	−203	0
3	14	78	49	99	85	46	−187	− 4
	21	74	49	81	78	67	−198	− 3
4	15	76	65	66	157	123	−210	− 1
	15	68	62	54	111	82	−199	0
5	16	60	31	131	85	49	−191	− 5
	22	61	40	128	95	59	−194	− 2
6	13	53	69	149	101	56	−187	+ 3
	20	78	67	155	90	56	−189	+ 1
7	22	51	26	102	110	65	−188	+ 6
	26	40	26	165	82	50	−181	+ 6
8	17	50	53	82	142	110	−207	− 1
	21	39	45	52	125	130	−214	− 4
10	13	54	52	130	109	46	−187	− 4
	22	57	47	117	79	53	−186	+ 2
11	13	78	70	75	241	358	−225	+ 5
	14	72	68	87	247	371	−226	+ 4
12	12	60	67	89	136	88	−202	− 1
	12	51	75	49	226	193	−215	+ 2
13	15	71	67	105	155	162	−215	− 1
	17	65	61	85	197	183	−220	− 4
14	13	68	68	75	216	210	−221	− 2
	15	69	73	75	193	173	−210	+ 5
15	17	54	56	31	169	141	−211	0
	19	52	55	46	174	136	−210	+ 1
16	19	61	41	98	127	73	−189	+ 8
	28	75	44	97	110	63	−191	+ 2
17	20	84	65	99	156	127	−215	− 6
	23	62	61	45	234	284	−227	− 2
18	19	68	43	288	84	44	−180	+ 1
	19	73	47	292	84	57	−186	+ 5
19	21	37	25	131	82	64	−193	+ 1
	34	30	20	230	67	33	−163	− 1
20	19	52	50	69	188	125	−208	+ 1
	21	56	48	76	205	197	−219	− 1
21	19	44	50	67	110	75	−193	+ 4
	21	58	49	60	189	219	−223	− 3
22	21	81	57	92	126	141	−218	− 7
	22	68	67	61	182	145	−215	− 3
23	13	62	56	80	154	68	−183	+12
	27	87	69	80	179	153	−211	+ 2
24	14	75	69	83	146	114	−207	0
	21	78	65	77	145	140	−210	+ 1
25	11	112	98	90	141	116	−206	+ 2
	14	107	86	83	189	145	−214	− 2
26	27	84	71	78	198	173	−215	0
	28	76	71	79	190	128	−205	+ 4
29	14	35	29	94	53	34	−160	+ 4
	22	44	19	118	65	41	−163	+14
31	13	27	30	22	256	183	−219	− 3
	16	26	27	29	202	164	−219	− 5
32	30	44	20	237	88	50	−177	+10
	34	46	20	237	100	59	−189	+ 2

all the calculations that follow *solely* refer, the means and standard deviations of sulphur, phosphorus and copper contents may be obtained from Tables III. to IX. for the whole 392 cans. Table X. shows the results; the fourth column is obtained on the assumption that the distributions of sulphur, phosphorus and copper contents in the population follow the Normal Law of Dispersion. This is very nearly true in the sample for sulphur and phosphorus, and approximately so for copper; distribution curves are not given, but may readily be constructed if required. The close approximation of the analyses to Normal Dispersion is good confirmation of the truly " random " nature of the sample.

TABLE X.—*Description of Tinplate Population.*

	Mean Content. %.	Standard Deviation. %.	Limits between which 95% of the Population lies. %.
Sulphur . . .	$0{\cdot}061_5$	0·017	0·029–0·094
Phosphorus . .	0·053	0·018	0·018–0·088
Copper . . .	0·101	0·049	0·005–0·198

(3) *Statistical Methods.*

In the correlation of the variates here studied, two methods have been used. The first, that of the " scatter diagram," in which any one variate is plotted against another, serves to give a qualitative indication of the degree of correlation of the variates; points lying on a smooth curve represent perfect correlation, points scattered at random indicate no correlation, while points such as those in Figs. 2 to 9 indicate some correlation. The second method, that of the " correlation coefficient," [16] gives a quantitative measure of the correlation, the " significance " of which (that is, the odds that the result truly represents the relationship of the variates in the population from which the sample was drawn, and is not due to chance sampling fluctuations) can be tested. If a variate X has a series of values X_1, X_2 . . . X_n in a sample of n individuals, with mean value $\Sigma X/n = \bar{X}$, and a variate Y has corresponding values Y_1, Y_2 . . . Y_n, mean $\Sigma Y/n = \bar{Y}$, then their *total correlation coefficient* r_{XY} is :

$$r_{XY} = \frac{\Sigma(X - \bar{X})(Y - \bar{Y})}{\sqrt{\Sigma(X - \bar{X})^2 \Sigma(Y - \bar{Y})^2}} = \frac{\Sigma XY - n\bar{X}\bar{Y}}{\sqrt{(\Sigma X^2 - n\bar{X}^2)(\Sigma Y^2 - n\bar{Y}^2)}}.$$

All correlation coefficients lie between $+1$ and -1; a sufficiently high positive value indicates that the variates increase together, a high negative value that one increases with decrease of the other. The odds that any given value is significant, *i.e.*, is due to a real association of the variates in the population from which the sample was drawn, and not to a chance effect in the small sample, may be

calculated for any size of sample by means of " Student's " " t test " [16] or Fisher's " z test "; [16] Fisher has provided tables of numerical values. Conventionally, a result is regarded as " strongly probable " if the probability of its occurring by chance is less than 0·05, *i.e.*, if the odds on its being a " real " result are better than 19 : 1; and as " practically certain " if its chance probability is less than 0·01, *i.e.*, an odds-on value of 99 : 1. The larger a sample, the smaller need be a correlation coefficient derived from it, for equal degree of significance.

When it is desired to eliminate the influence of a third variate Z on the association of X and Y, *i.e.*, to find what the correlation of X and Y would be for a constant value of Z, the *first-order partial correlation coefficient of* X *and* Y, with Z constant, may be calculated as :

$$r_{XY.Z} = \frac{r_{XY} - r_{XZ} \cdot r_{YZ}}{\sqrt{(1 - r_{XZ}^2)(1 - r_{YZ}^2)}},$$

and a further variate W may be eliminated in the second-order partial correlation coefficient :

$$r_{XY.ZW} = \frac{r_{XY.Z} - r_{XW.Z} \cdot r_{YW.Z}}{\sqrt{(1 - r_{XW.Z}^2)(1 - r_{YW.Z}^2)}}.$$

The significance of these partial correlation coefficients may be tested as in the case of total correlation coefficients.

In the present experiments, each sample consists of 56 cans, 2 from each of 28 random cases of tinplate. However, in calculations of significance the sample size must not be taken as 56, since the 28 pairs naturally show very considerable correspondence within each pair. If this correspondence were complete, *i.e.*, if the pairs were reproducible duplicates, the sample size would be 28; but since this is far from being the case, it is fair to take, for the purpose of significance calculations, a sample size somewhat greater than this. As a conservative estimate, we may take the apparent sample size as 34, *i.e.*, suppose the 28 partly corresponding cans, one of each pair, to be equivalent to 6 completely independent ones; and all significance calculations that follow are based on this value. It would be possible, by means of a lengthy and complicated analysis of variance, to arrive at a mathematically rigid solution of this problem; but it is felt that the arbitrarily chosen figure of 34 is sufficiently conservative to make this work unnecessary.

Small, insignificant correlation coefficients do not necessarily mean that the variates are unrelated; they may be related non-rectilinearly, which will be apparent on the scatter diagram; or the relationship may be masked by the variation of other un-eliminated variates; or the experimental data may not be numerous or accurate enough to show the relation. Each of these causes of insignificance will be noted in certain of the coefficients here reported.

(4) *Correlation of Time of Formation of Hydrogen-Swell with Steel-Base Corrosion in Citric Acid.*

Fig. 2 shows scatter diagrams of the time of formation of hydrogen-swell, T (weeks), and the weight-loss, M (mg. per 72 hr.), of a 7·5 × 2·5-cm. specimen of the steel base of the can body in 0·5% citric acid, under "closed" conditions. There is clearly a fairly high negative correlation between T and the "artificial" corrosion rate M of the steel, for most of the packs. The correlation coefficients r_{TM} are given in Table XI., with the probabilities p that the values are due to chance; in several cases p is exceedingly small. In this Table (and in Tables XII. and XIII.), those correlation coefficients that are significant (strong probability, $p < 0{\cdot}05$) are underlined, and those that are very significant (practical certainty, $p < 0{\cdot}01$) are in heavy type.

TABLE XI.—*Correlation of Time of Formation of Hydrogen-Swell,* T, *with Steel-Base Corrosion Rate under "Closed" Conditions,* M.

Fruit.	r_{TM}.	p.
Blackcurrants . . .	**−0·687**	$2{\cdot}8 \times 10^{-6}$
Cherries (sweet) . . .	**−0·439**	$8{\cdot}5 \times 10^{-3}$
Gooseberries	**−0·618**	$5{\cdot}4 \times 10^{-5}$
Loganberries	**−0·496**	$2{\cdot}4 \times 10^{-3}$
Pershore plums . . .	**−0·486**	$3{\cdot}0 \times 10^{-3}$
Raspberries	−0·406	$1{\cdot}7 \times 10^{-2}$
Strawberries	−0·225	$2{\cdot}0 \times 10^{-1}$

Evidently in the cases of blackcurrants, cherries, gooseberries, loganberries, Pershore plums and raspberries, a short time of formation of hydrogen-swell in the can is significantly associated with a rapid "artificial" corrosion rate of the steel base of the can body; and if it had been experimentally possible to take the bottom end of the can also into account, the correlation would doubtless have been still greater. It may be concluded that:

(1) The nature of the steel base is one factor determining the rate of failure of the can.

(2) The "artificial" corrosion rate M of the steel base gives a very rough indication of the relative life of the can. (A closer indication can doubtless be obtained by corrosion experiments with the steel base in the appropriate fruit extracts, as suggested by a few experiments of Morris[7] and of Rhodes;[9] experiments of this kind are in hand.) This relationship was suggested by Morris[17] when he pointed out the great variability of the steel-base corrosion rate in citric acid, and is now experimentally confirmed.

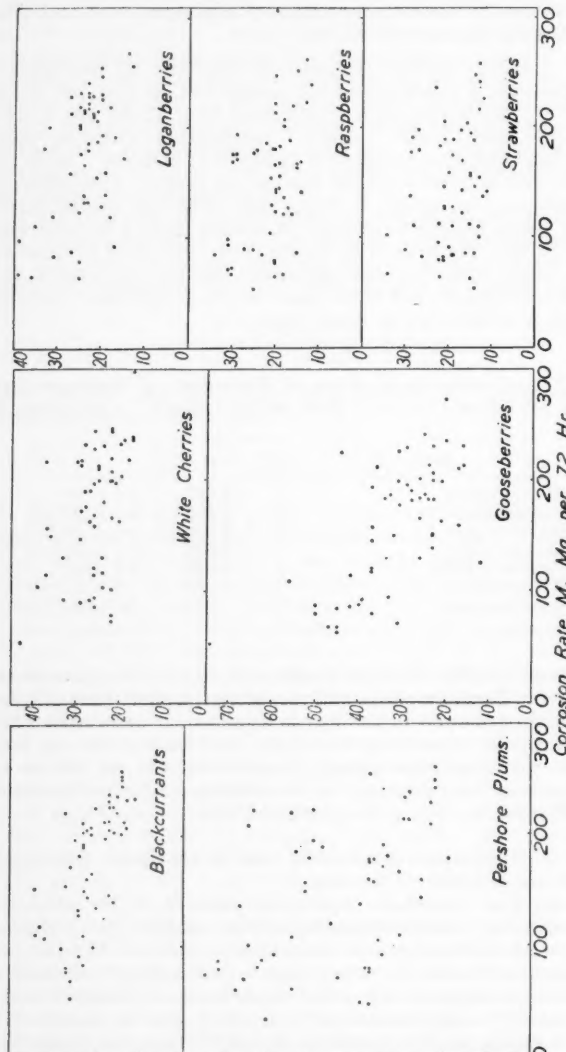

FIG. 2.—Correlation of Hydrogen-Swell Formation with Steel-Base Corrosion in Citric Acid.

Fig. 3 is a scatter diagram of the weight-loss M (closed conditions) against the weight-loss H (mg. per 72 hr.) of the 3·5 × 2·5-cm. specimens under "open" conditions. Reasonably close correlation is found; no correlation coefficient has been calculated as the relationship is clearly not rectilinear. The best curve

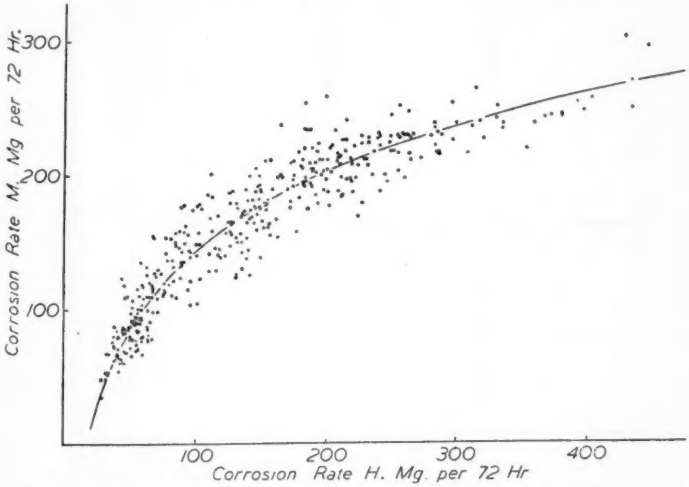

FIG. 3.—Correlation of Steel-Base Corrosion in Citric Acid under "Closed" Conditions with that under "Open" Conditions.

through the points, fitted freehand, is very nearly expressed by the empirical equation:

$$M = 200 \log_{10} H - 255,$$

which may be used for approximate conversions of M to H and *vice-versa*. Evidently the two corrosion techniques give results in general agreement; the "closed" technique is probably somewhat nearer to the actual conditions within a can.

(5) *Correlation of Time of Formation of Hydrogen-Swell with Steel-Base Composition.*

Fig. 4 shows scatter diagrams of the time of formation of hydrogen-swell, T, against the "weighted mean" phosphorus content of the steel base, P, while Fig. 5 shows the similar diagrams of T against the mean copper content, Cu. Considerable correlation is evident in many cases; high P usually favours low T,

whereas high Cu usually favours high *T*. These correlations are, however, in every case enhanced by the association of ***high P with low Cu*** in the sample. In order to separate the various factors,

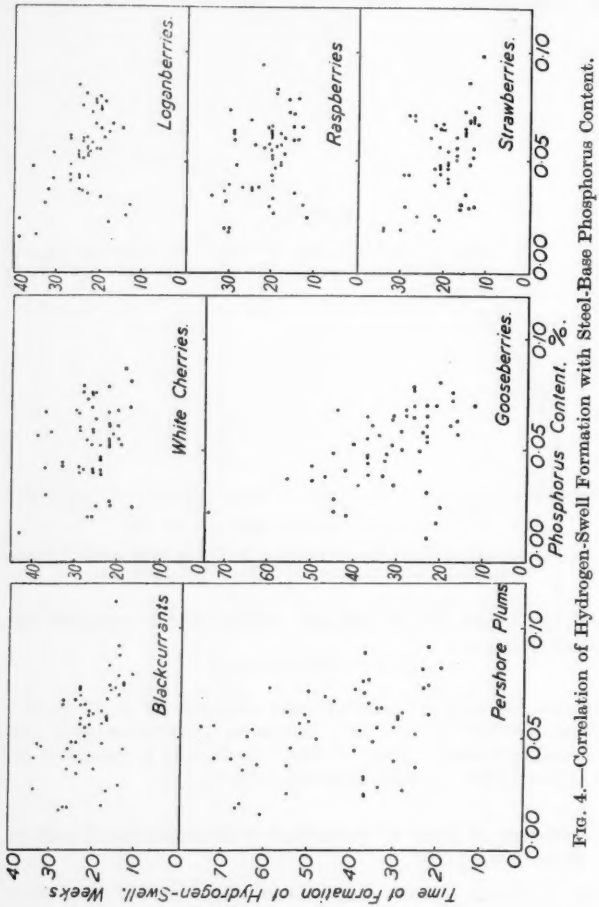

FIG. 4.—Correlation of Hydrogen-Swell Formation with Steel-Base Phosphorus Content.

including also sulphur, all the necessary total, and first- and second-order partial, correlation coefficients have been calculated; the relevant results are given in Table XII.

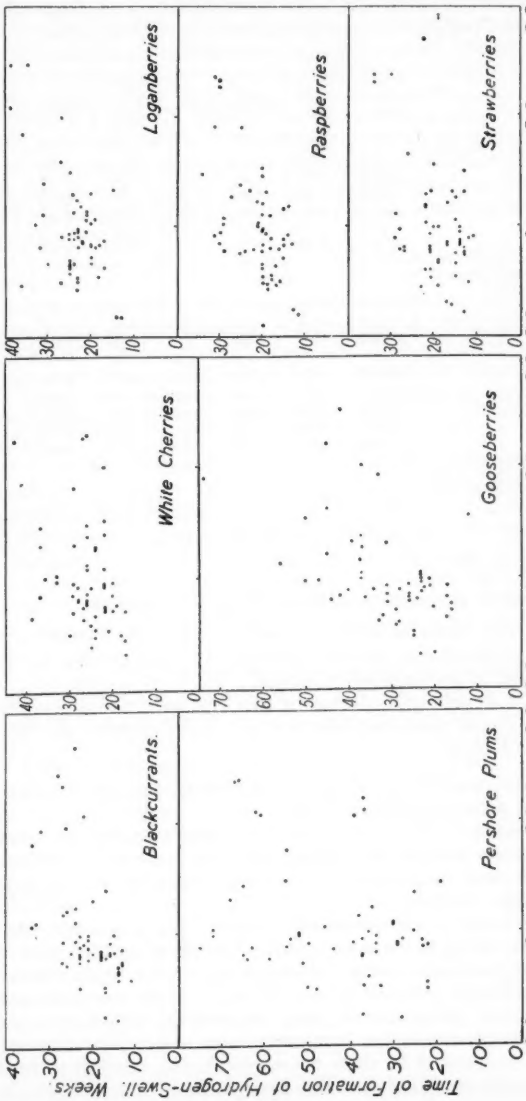

Fig. 5.—Correlation of Hydrogen-Swell Formation with Steel-Base Copper Content.

TABLE XII.—*Correlation of Time of Formation of Hydrogen-Swell, T, with Steel-Base Composition Variates, S, P and Cu.*

	Black-currants.	White Cherries.	Gooseberries.	Loganberries.	Yellow Pershore Plums.	Raspberries.	Strawberries.
Total Correlation Coefficients.							
r_{TS}	−0·327	−0·018	−0·245	−0·134	−0·082	−0·003	−0·226
r_{TP}	**−0·536**	−0·230	**−0·466**	−0·346	−0·391	−0·363	**−0·465**
r_{TCu}	**+0·548**	+0·320	**+0·502**	**+0·652**	+0·286	**+0·568**	+0·372
r_{SP}	**+0·792**	**+0·714**	**+0·767**	**+0·771**	**+0·664**	**+0·690**	**+0·784**
r_{SCu}	−0·121	−0·162	−0·072	−0·072	−0·130	+0·010	−0·073
r_{PCu}	−0·409	**−0·590**	−0·371	−0·357	**−0·528**	**−0·499**	−0·393
First-Order Partial Correlation Coefficients.							
$r_{TS.P}$	+0·190	+0·214	+0·199	+0·223	+0·259	+0·367	+0·253
$r_{TS.Cu}$	−0·314	+0·036	−0·242	−0·115	−0·047	−0·010	−0·215
$r_{TP.S}$	**−0·480**	−0·310	**−0·448**	−0·385	**−0·452**	**−0·499**	**−0·477**
$r_{TP.Cu}$	−0·408	−0·053	−0·349	−0·160	−0·295	−0·113	−0·374
$r_{TCu.S}$	**+0·542**	+0·322	**+0·501**	**+0·650**	+0·279	**+0·568**	+0·366
$r_{TCu.P}$	+0·426	+0·235	+0·401	**+0·603**	+0·102	**+0·479**	+0·232
$r_{SP.Cu}$	**+0·820**	**+0·776**	**+0·799**	**+0·800**	**+0·708**	**+0·802**	**+0·824**
$r_{SCu.P}$	+0·366	**+0·458**	+0·356	+0·342	+0·349	**+0·564**	+0·412
$r_{PCu.S}$	**−0·518**	**−0·686**	**−0·493**	**−0·475**	**−0·472**	**−0·698**	**−0·543**
Second-Order Partial Correlation Coefficients.							
$r_{TS.PCu}$	+0·040	+0·123	+0·064	+0·023	+0·240	+0·134	+0·178
$r_{TP.SCu}$	−0·278	−0·129	−0·266	−0·115	−0·371	−0·174	−0·356
$r_{TCu.SP}$	+0·391	+0·158	+0·361	**+0·575**	−0·013	+0·353	+0·145

These results are of interest from two points of view :

(1) The metallurgical interest of the association of the minor constituents sulphur, phosphorus and copper in dead-mild steel of the tinplate type, and

(2) The primary interest of this research, the discovery of factors in the steel-base composition that influence the rate of failure of cans.

The purely metallurgical correlations, *i.e.*, the coefficients not involving T, will be considered first.

(*a*) r_{SP}, $r_{SP\,.\,Cu}$.—Highly significant positive values are always found; thus an increase of sulphur content is strongly associated with an increase of phosphorus content, whether or not copper content is kept constant.

(*b*) r_{SCu}, $r_{SCu\,.\,P}$.—Insignificant values of r_{SCu} are always found; thus, there is no association of sulphur content with any particular copper content when phosphorus content varies naturally. But the significant positive values of $r_{SCu\,.\,P}$ show that increase of sulphur content is associated with increase of copper content if phosphorus content is kept constant; this association of sulphur and copper is masked in their total correlation coefficient by the marked association of sulphur and phosphorus.

(*c*) r_{PCu}, $r_{PCu\,.\,S}$.—Significant negative values are always found; thus, increase of phosphorus content is associated with decrease of copper content, whether or not sulphur content is kept constant.

These results may be summarised as follows: A high-sulphur steel sheet tends to be high in phosphorus and *vice versa*. A high-copper steel tends to be low in phosphorus, but not necessarily in sulphur; indeed, in a steel of fixed phosphorus content, increase of copper content tends to be associated with increase of sulphur content.

In the light of these results, the correlation of can-failure with the various metallurgical factors, *i.e.*, those coefficients involving T, may be considered.

(*d*) r_{TS}, $r_{TS\,.\,P}$, $r_{TS\,.\,Cu}$, $r_{TS\,.\,PCu}$.—Insignificant values (with one exception), are found; thus decrease of rate of can-failure (increase of T) is not associated with any particular sulphur content of the steel base (within the limits of the population being investigated), either when phosphorus and copper contents are allowed to vary, or when one or both of them are kept constant at values near their average values in tinplate steel. The exception, $r_{TS\,.\,P} = +\,0{\cdot}367$ for raspberries, is due to a particularly high $r_{SCu\,.\,P}$ in this sample (*see* later).

(*e*) r_{TP}, $r_{TP\,.\,S}$.—Significant negative values are found for all packs except cherries; thus, with this exception, increase of T is associated with decrease of phosphorus content, whether or not sulphur content is kept constant. This does not necessarily mean that decrease of rate of can-failure is *due* to decrease of phosphorus content, for it will be remembered (*see* (*c*) above) that decrease of phosphorus content is associated with increase of copper content, which may be the more operative factor. This is shown by $r_{TP\,.\,SCu}$ below.

(*f*) $r_{TP\,.\,SCu}$.—Significant negative values are found only for Pershore plums and strawberries; thus, for these packs only, increase of T is associated with decrease of phosphorus content (or of some uneliminated factor associated with phosphorus content) when sulphur and copper contents are kept constant.

(*g*) r_{TCu}, $r_{TCu\,.\,S}$.—Significant positive values are found for all packs except cherries and plums; thus, with these exceptions, decrease of rate of can-failure (increase of T) is associated with increase of copper content, whether or not sulphur content is kept constant. This does not necessarily mean that decrease of rate of can-failure is *due* to increase of copper content, by the same reasoning as that applied in (*e*). The matter is cleared up by $r_{TCu\,.\,SP}$:

(*h*) $r_{TCu\,.\,SP}$.—Significant positive values are found only for the packs of blackcurrants, gooseberries, loganberries and raspberries; thus, in these packs only, increase of T is associated with increase of copper content (or of some uneliminated factor associated with copper content), when sulphur and phosphorus contents are kept constant.

Having thus formally stated the meaning of the results, we

may put the matter in a more practical way as follows : For packs of blackcurrants, gooseberries, loganberries, plums, raspberries and strawberries, in double-lacquered cans made from pack-rolled tinplate (1½ lb. of tin per basis box) as obtainable on the British market, it is very probable that tinplates made from steel bases higher in copper, and lower in phosphorus, give a slower incidence of hydrogen-swells. For blackcurrants, gooseberries, loganberries and raspberries, the operative factor producing the desirable result is very probably the high copper; for plums and strawberries, it is very probably the lower phosphorus. For packs of sweet cherries, the copper and phosphorus contents are immaterial. For all the above fruits, the sulphur content is immaterial.

The *amount* of improvement to be expected is of importance. It is possible to calculate regression equations for T on P and Cu that indicate the expected life of a can at any given phosphorus or copper content. The scatter involved, however, makes the expected error in such results rather large. It is better to adopt the qualitative procedure of inspection of the scatter diagrams of Figs. 4 and 5. Under random conditions of tinplate utilisation, the first 10% of can-failures may naturally be expected at values of T corresponding to nearly the lowest found on these diagrams; while under " ideal " conditions of specification, the first 10% of can-failures may be expected at values of T corresponding to nearly the highest shown. Thus, a high-copper, low-phosphorus specification should, at a rough but conservative estimate, double the time at which the first 10% of failures may be expected, for packs of those fruits for which the steel-base composition has been shown to be significant.

The practical upper limit of copper content, beyond which little improvement can be expected, is probably in the neighbourhood of 0·2%; this limit is suggested by an inspection of Fig. 4 and is further discussed in the next section. The practical lower limit of phosphorus is fixed by pack-rolling considerations at about 0·04%.

All these conclusions take no account of the variable nature of the fruits themselves, which has been rightly emphasised as a most important factor by many authorities.[6, 8, 15] All fruits contain little-understood accelerators and inhibitors of corrosion, doubtless in varied amounts depending on conditions of growing and canning. However, since high-copper, low-phosphorus tinplate has been shown to be generally favourable for these several packs of different representative fruits, its general use for such fruits may be expected to be advantageous on the average.

(6) *Correlation of " Artificial " Corrosion-Rates of Steel-Base with Steel-Base Composition and with Corrosion-Potential.*

Fig. 6 is the scatter diagram of corrosion rate M against the weighted-mean phosphorus content; every can of the 7 packs, *i.e.*, 392 in all, is included. Although M could only be found for the

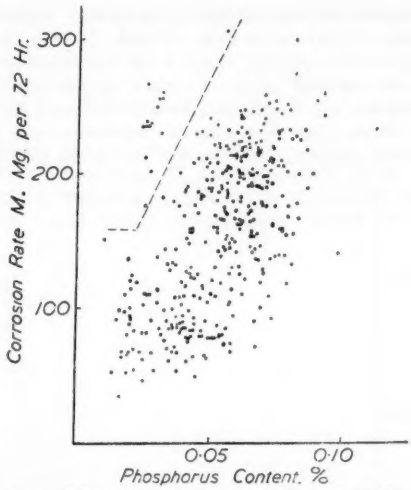

FIG. 6.—Correlation of Steel-Base Corrosion in Citric Acid (Closed Conditions) with Phosphorus Content. (The points above the broken line represent material having especially low *copper* content, and mask the correlation if this fact is not borne in mind.)

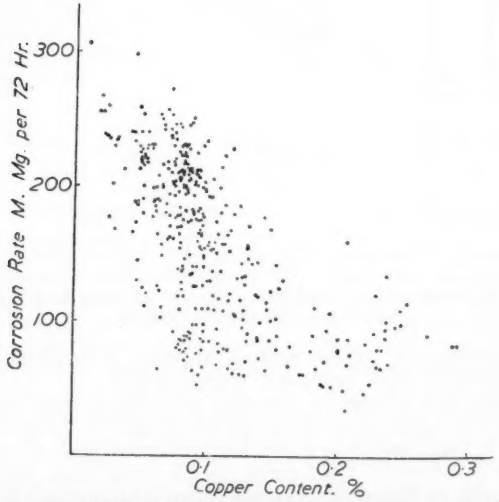

FIG. 7.—Correlation of Steel-Base Corrosion in Citric Acid (Closed Conditions) with Copper Content.

can body, considerable correlation is observed; evidently increase of corrosion rate is associated with increase of phosphorus content over the range investigated. Fig. 7 is the scatter diagram of corrosion rate M against copper content, while Fig. 8 is the corresponding diagram for corrosion rate H. In both diagrams there is definite evidence that decrease of corrosion rate is associated with increase of copper content, up to about 0·2% of copper.

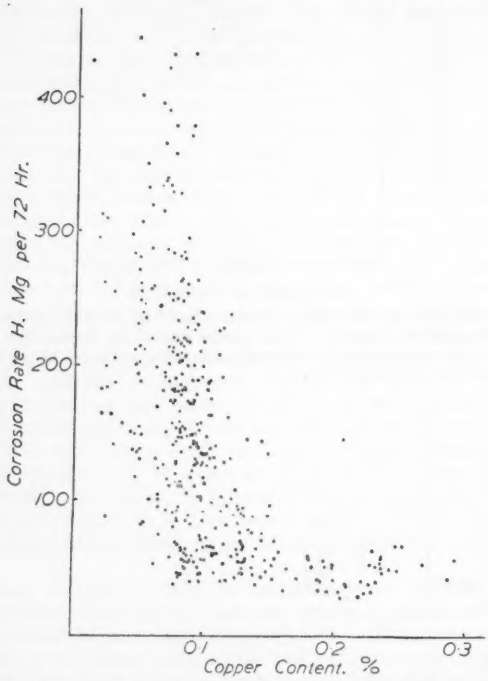

FIG. 8.—Correlation of Steel-Base Corrosion in Citric Acid (Open Conditions) with Copper Content.

Further increase of copper content appears, if anything, to be associated with a slight increase of corrosion rate.

The *amount* of change of corrosion rate with a given change of phosphorus or copper content, as given by Figs. 6, 7 and 8, refers of course to the population of steels investigated, with all variables "roaming" naturally. But since, as has been seen, increase of phosphorus is, in the population, associated with decrease of copper content, the change of corrosion rate for a given change of phosphorus

content, *if copper content were kept constant,* would be considerably less than that given by Fig. 6; and similarly for a change of copper content if phosphorus were kept constant. These results are thus in general agreement with those of Bardenheur and Thanheiser [1] and of Edwards, Phillips and Thomas [3] for somewhat different materials.

Fig. 9 shows the relationship between the corrosion rate, H, and the corrosion potential, E, measured after 72 hr. As explained by Hoar and Havenhand,[2] each point represents the intersection of the cathodic and anodic polarisation curves for the particular

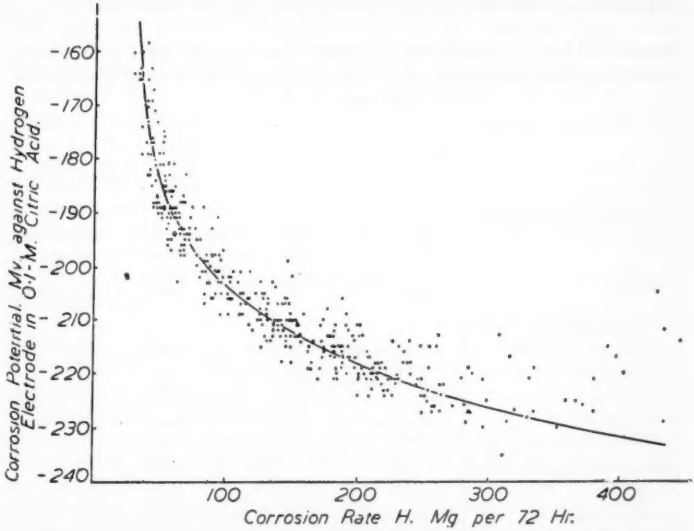

FIG. 9.—Relationship between Corrosion Rate and Corrosion Potential.

specimen; for cathode and anode have polarised to practically the same potential, and the rates of their respective reactions $2H^+ + 2\varepsilon \rightarrow H_2$ and $Fe \rightarrow Fe^{++} + 2\varepsilon$ are both equal to the corrosion rate and equivalent to the corrosion current. Since the points lie on or near a logarithmic curve having the form of a cathodic polarisation curve, it is clear that the *main* differences between the steels lie in their *anodic* polarisation. However, many of the "fast" steels are represented by points lying above the general curve of Fig. 9; as explained in the previous paper,[2] this indicates that their rapid corrosion is partly due to especially efficient cathodes, giving smaller cathodic polarisation than usual. ΔE of Tables III. to IX. is the height, in millivolts, of each corrosion-potential/

corrosion-rate point above the general curve, and is thus a measure of the variation of cathodic efficiency found in the 392 specimens. It may, for convenience, be termed the " cathodic increment."

(7) *Correlation of Cathodic Increment with Steel-Base Composition and with Time of Formation of Hydrogen-Swell.*

We may now consider how far the cathodic increment is associated with the sulphur, phosphorus and copper contents of the steel base, and whether it is a factor of importance in the rate of formation of hydrogen-swells in the fruit packs. The relevant correlation coefficients, as calculated, are given in Table XIII.

TABLE XIII.—*Correlation of Cathodic Increment,* ΔE, *with Steel-Base Composition Variates, S, P and Cu, and with Time of Formation of Hydrogen-Swell,* T.

	Black-currants.	White Cherries.	Gooseberries.	Loganberries.	Yellow Pershore Plums.	Raspberries.	Strawberries.
Total Correlation Coefficients.							
$r_{T\Delta E}$	−0·151	**−0·556**	**−0·475**	−0·263	−0·208	+0·126	+0·164
$r_{S\Delta E}$	−0·029	−0·156	+0·002	+0·017	−0·012	−0·249	−0·158
$r_{P\Delta E}$	+0·193	+0·283	+0·346	+0·183	**+0·472**	+0·085	−0·211
$r_{Cu\Delta E}$	+0·025	−0·258	−0·201	+0·010	**−0·462**	−0·179	+0·264
First-Order Partial Correlation Coefficients.							
$r_{S\Delta E.P.}$	−0·304	**−0·533**	**−0·445**	−0·198	**−0·495**	−0·427	+0·012
$r_{S\Delta E.Cu.}$	−0·026	−0·208	−0·017	+0·018	−0·082	−0·252	−0·144
$r_{P\Delta E.S.}$	+0·354	**+0·570**	**+0·542**	+0·267	**+0·642**	+0·367	−0·142
$r_{P\Delta E.Cu.}$	+0·223	+0·167	+0·299	+0·200	+0·302	−0·005	−0·121
$r_{Cu\Delta E.S.}$	+0·021	−0·291	−0·202	+0·012	**−0·468**	−0·182	+0·256
$r_{Cu\Delta E.P.}$	+0·116	−0·118	−0·083	+0·083	−0·284	−0·158	+0·201
Second-Order Partial Correlation Coefficients.							
$r_{S\Delta E.PCu}$	−0·375	**−0·543**	−0·445	−0·242	−0·440	−0·415	−0·080
$r_{P\Delta E.SCu}$	+0·427	**+0·533**	**+0·519**	+0·309	**+0·512**	+0·341	−0·003
$r_{Cu\Delta E.SP}$	+0·256	+0·168	+0·090	+0·163	−0·137	+0·112	+0·216
Third-Order Partial Correlation Coefficients.							
$r_{T\Delta E.SPCu}$	−0·112	**−0·539**	−0·390	−0·340	+0·121	+0·374	+0·046
$r_{TS.PCu\Delta E}$	−0·005	−0·218	−0·125	−0·064	+0·267	+0·288	+0·180
$r_{TP.SCu\Delta E}$	−0·210	+0·209	−0·036	−0·005	−0·378	−0·302	−0·356
$r_{TCu.SP\Delta E}$	+0·404	+0·283	+0·415	**+0·623**	+0·030	+0·339	+0·132

In considering these results, it must be borne in mind (*a*) that ΔE could be determined only for the can body, whereas the variates *T*, S, P and Cu are determined as weighted means for the body and end, and (*b*) that the values of ΔE are very much less proportionately accurate than those of the other variates. But even with these limitations, the results give a considerable amount of information.

(*a*) $r_{S\Delta E}$, $r_{S\Delta E \cdot P}$, $r_{S\Delta E \cdot Cu}$, $r_{S\Delta E \cdot PCu}$.—Insignificant values of $r_{S\Delta E}$ and $r_{S\Delta E \cdot Cu}$ are always found; thus there is no association between cathodic increment and sulphur content when phosphorus and copper contents vary naturally or when copper content is kept constant. But the several significant negative values of $r_{S\Delta E \cdot P}$ and $r_{S\Delta E \cdot PCu}$ * show that increase of cathodic increment is associated with decrease of sulphur content when phosphorus content is kept constant. The weighted-mean value of $r_{S\Delta E \cdot PCu}$ for all seven samples may be estimated by Fisher's "z" transformation [16] as $-0{\cdot}370$, which is significant.

(*b*) $r_{P\Delta E}$, $r_{P\Delta E \cdot S}$, $r_{P\Delta E \cdot Cu}$, $r_{P\Delta E \cdot SCu}$.—Insignificant values of $r_{P\Delta E}$ and $r_{P\Delta E \cdot Cu}$ are nearly always found, while the values of $r_{P\Delta E \cdot S}$ and $r_{P\Delta E \cdot SCu}$ are nearly all significant and positive.* Thus, by reasoning similar to that in (*a*) above, increase of cathodic increment is associated with increase of phosphorus content if, and only if, sulphur content is kept constant. The weighted-mean value for $r_{P\Delta E \cdot SCu}$ is $+ 0{\cdot}388$, which is significant.

(*c*) $r_{Cu\Delta E}$, $r_{Cu\Delta E \cdot S}$, $r_{Cu\Delta E \cdot P}$, $r_{Cu\Delta E \cdot SP}$.—Insignificant values are always found, with two exceptions due to the negative correlation of copper and phosphorus; thus there is no association of cathodic increment with copper content, whether or not sulphur and phosphorus contents are kept constant.

The only coefficients involving T that are of especial interest are the following:

(*d*) $r_{T\Delta E}$, $r_{T\Delta E \cdot SPCu}$.—Significant negative values are found only for white cherries and gooseberries: thus, for these packs only, increase of T is associated with decrease of cathodic increment, whether or not sulphur, phosphorus and copper contents are kept constant. The *positive* value of $r_{T\Delta E \cdot SPCu}$, $+ 0{\cdot}374$, found for raspberries, is just significant, but may be a "fluke" due to sampling fluctuations, since the odds against its occurring by chance are only some 25 to 1; in the absence of any other similar value or of any theoretical reason for expecting it, it cannot be accepted as evidence of a real association of increase of T with increase of cathodic increment.

(*e*) $r_{TS \cdot PCu\Delta E}$, $r_{TP \cdot SCu\Delta E}$, $r_{TCu \cdot SP\Delta E}$.—The effect of eliminating the influence of ΔE from the previously found second-order coefficients $r_{TS \cdot PCu}$, &c., is seen by comparison with Table XII. to be negligible except for the packs of cherries, gooseberries and loganberries, where the coefficients $r_{T\Delta E \cdot SPCu}$ are considerable; in these cases, the values of $r_{TCu \cdot SP}$ are enhanced in $r_{TCu \cdot SP\Delta E}$. This is to be expected: if a factor is of importance, its elimination increases the significance of the correlation of other factors; if it is not important, its elimination has no effect.

These results may be summarised in a practical way: In steels of the type under study, it is very probable that those having

* The few insignificant values are doubtless due to experimental error in ΔE.

higher phosphorus content (sulphur being kept constant) possess cathodic points of greater efficiency for the reaction $2H^+ + 2\varepsilon \rightarrow 2H_2$ when they corrode in citric acid; and that those having higher sulphur content (phosphorus being kept constant) possess less efficient cathodes. Copper content is immaterial in this respect. Furthermore, good cathodic efficiency of the steel base for the above reaction (sulphur, phosphorus and copper contents being constant) very probably leads to more rapid production of hydrogen-swells in lacquered-can packs of white cherries and gooseberries, but is immaterial in the other packs here reported.

IV.—General Discussion.

(1) *The Metallurgical Correlations.*

The composition correlations between sulphur, phosphorus and copper contents are of interest to the metallurgist, and some tentative observations on their cause may be made. The high positive correlation between sulphur and phosphorus contents is undoubtedly due to two well-established causes: (*a*) The removal of these elements during smelting and steelmaking is similar, depending on the volatility and acidity of the oxides, and (*b*) the elements segregate together in the ingot, which naturally further favours their correlation in the finished sheets from different parts of the ingot. The negative correlation between phosphorus and copper may be partly caused by the variation in the proportions of pig iron and scrap steel used in the manufacture of tinplate steel base. The pig iron will tend to be higher in phosphorus, but lower in copper, than the scrap; thus steel base made from a charge with a high proportion of pig to scrap will tend to be high-phosphorus/low-copper, while that made from a high proportion of scrap will tend to be high-copper/low-phosphorus. This matter requires further investigation. The positive correlation between sulphur and copper *when phosphorus is kept constant* could well be due to co-segregation of copper and sulphur in the ingot; this possibility is suggested by the recent work of Skapski, Kotlinski and Goslawski,[18] who put forward chemical evidence to show that sulphur, even in low-copper steels, exists almost entirely as manganese and *copper* sulphides.

(2) *The Cathodic Increment.*

It is clear from $r_{S\Delta E \,.\, PCu}$ and $r_{P\Delta E \,.\, SCu}$ (section III. (7), (*a*) and (*b*)) that increase of sulphur content (or some uneliminated factor associated with it) is associated with decrease of ΔE, while increase of phosphorus content (with the same reservation) is associated with increase of ΔE. If these associations are indeed causes and effects, sulphur is a cathodic inhibitor and phosphorus a cathodic stimulator. The sulphur effect is doubtless a "poisoning" of the cathodic points, as indicated in previous work[2]; it should not be forgotten that hydrogen sulphide is *also* an *anodic* stimulator.[2, 19]

The phosphorus effect may be due to indirect influences, and requires further investigation. But there are also other influences on the cathodic process, as shown by the values of $r_{T\Delta E}$ and $r_{T\Delta E.SPCu}$ for cherries and gooseberries; elimination of the composition variates scarcely affects the significant correlation of T and ΔE. A preliminary micrographic examination of some of the present specimens of steel has supported the suggestion, previously put forward,[2] of a positive correlation between the cathodic increment and the amount of cementite in the steel, but a more comprehensive investigation will be necessary to establish the matter.

(3) *Comparison of Results with Previous Steel-Base Researches.*

The present results for the influence of copper content on the rate of hydrogen production under canning conditions are in line with the work of Bardenheuer and Thanheiser,[1] Hoar and Havenhand,[2] and Edwards, Phillips and Thomas[3] on the corrosion

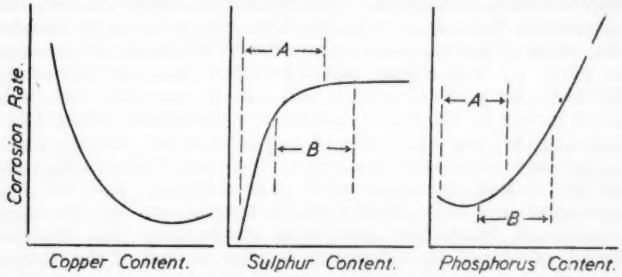

FIG. 10.—Possible Types of Relationship between Corrosion Rate and Composition Variates.

of mild steels in acid media; all these investigators, with widely different types of material, found a decidedly retarding influence of copper on the corrosion rate. In the previous researches, however, the accelerating influence of sulphur was stressed by Hoar, that of phosphorus by Edwards, and that of both elements by Bardenheuer, whereas in the present work sulphur has been shown to be without influence, and phosphorus to be an accelerator only in certain cases, under canning conditions. There are several reasons for these different results. In the first place, perfect agreement between steel-base corrosion tests in pure acids and canning tests where the corrosive agent is a complicated fruit-juice mixture, is not attained, and indeed is not to be expected. Secondly, the materials used by Bardenheuer and by Edwards were synthetic steels, many of them not of the tinplate type, while those used by Hoar were a random sample of tinplate steels *as obtainable in Great Britain some years ago*, and contained numerous individual steels of Continental origin, very low in sulphur, phosphorus and copper.

Perfect agreement between such materials and a random sample of present-day British tinplate steel base is, again, not to be expected. The schematic diagrams of Fig. 10 may make the point even clearer. It is perfectly possible that, just as there is some evidence for a non-rectilinear relationship, Fig. 10(*a*), between corrosion rate and copper content, the similar relationships between corrosion rate and sulphur and phosphorus contents are non-rectilinear, Fig. 10, (*b*) and (*c*). Thus, results obtained for linear correlation coefficients in Hoar's previous work, where the population studied lay in the region *A*, would naturally be different from those now obtained with population *B*, even in the case of the present citric-acid corrosion tests, as well as in the canning experiments.

(4) *Comparison of Results with Previous Canning Researches.*

The present results do not conflict with previous canning experiments, and positive agreement occurs in certain cases where the researches have overlapped. The matter of copper content may be considered first, since it has been the subject of several studies. In the work of the American committee,[4] decidedly better results were given by high-copper (0·3–0·4%) steel than by low-copper (0·05–0·1%) for packs of peaches and cider in enamelled (lacquered) cans, as judged by the time taken for 10% of the individual cans in the packs to fail (*loc. cit.*, Table 43, p. 129; the time for 10% failure of a pack is a fairly good measure of its commercial success—more than 10% failure makes the whole pack suspect); while the high-copper steel gave only slightly poorer results than the low-copper for packs of blueberries and black raspberries. The beneficial influence of copper, though nearly as great as that of the titanium treatment that was the main theme of the American committee's study, is not stressed in their report to the extent that the data warrant. McConkie [5] compared steels having copper contents of 0·08, 0·5, 1·0, 1·5 and 2·0%, for unlacquered-can packs of Royal Anne cherries, and lacquered-can packs of Black Lambert cherries, strawberries and loganberries. The three higher-copper steels were uniformly poorer than the " blank " 0·08% copper steel, but the 0·5% copper steel, though inferior to the " blank " for both kinds of cherries, was slightly superior for strawberries and definitely so for loganberries. Vaurio, Clark and Lueck [8] have recently reported that copper above 0·1% is detrimental for unlacquered-can packs of Royal Anne cherries and dried prunes in syrup, and for lacquered-can packs of red sour pitted and black cherries, but that it is without influence on unlacquered-can packs of peaches and pears, or on lacquered-can packs of loganberries; but these results refer to *strip steel very low in sulphur and phosphorus*. In fact, it will be noted that the previous researches differ from the present work in that either (*a*) the limits of copper investigated or (*b*) the type of steel used, or (*c*) the fruits used are different; there are therefore no points of disagreement in the results.

As a *speculative generalisation*, it may be suggested that, for many rapidly-corroding fruits in lacquered cans, increase of the steel-base copper content is at first beneficial but finally detrimental and that the optimum copper content is about 0·2% in the case of blackcurrants, gooseberries, loganberries and raspberries, for pack-rolled tinplate of an average phosphorus content of 0·055%, but is considerably lower both for cherries and for low-metalloid strip plate. This generalisation would cover all the results that have so far been obtained, but must not be regarded as in any sense proved; it is put forward as a mere hypothesis, to be tested.

With regard to phosphorus content, the American committee's [4] data show rather indistinct evidence for a detrimental influence of high phosphorus content (up to 0·15%) in certain cases, while a comparison by Hirst and Adam [6] of tinplates containing respectively 0·165 and 0·027% of phosphorus showed that the former was distinctly inferior for packs of loganberries, greengages and Victoria plums. In the present random sample of tinplate, most individuals lie between 0·03 and 0·08% of phosphorus, yet a significant influence appears in the case of Pershore plums and strawberries, in the same sense as that suggested by the previous work.

(5) "*Typical*" *Tinplates.*

It may be of interest to give approximate mean values of the composition and "artificial" corrosion behaviour for typical "poor," "average" and "good" tinplates as deduced from the present sample (Table XIV.). It is necessary to emphasise that these figures relate only to pack-rolled tinplate as at present on the British market, and that the descriptions "poor," "average" and "good" refer only to the likely behaviour of the tinplates when used for packing acid fruits of the kinds here discussed.

TABLE XIV.—*Characteristics of Typical Tinplates.*

	S. %.	P. %.	Cu. %.	*M.* Mg. per 72 hr.	*H.* Mg. per 72 hr.	*E.* Mv., against Hydrogen in 0·1 *M* Citric Acid.
"Poor" .	0·08	0·075	0·07	230	270	−213 to −229
"Average" .	0·06	0·055	0·10	160	120	−201 to −214
"Good" .	0·04	0·04 or less	0·16	80	50	−176 to −196

The least negative values of *E* given for the three "typical" cases correspond to the most positive "cathodic increments."

V.—SUMMARISED CONCLUSIONS.

(1) The steel base of the (pack-rolled) tinplate at present on the British market has the average composition: Sulphur 0·03–

0·09%, mean 0·06%; phosphorus 0·02–0·09%, mean 0·055%; copper 0·03–0·22%, mean 0·10%. *All the following results refer to this type of steel base only.*

(2) For the finished sheets of this material, high sulphur content is associated with high phosphorus content, and high phosphorus content with low copper content; but for a fixed phosphorus content, the higher-sulphur steels tend also to be higher in copper. Tentative suggestions for the causes of these associations are made.

(3) A more rapid formation of hydrogen-swells in cans of fruit was significantly associated with a higher rate of corrosion of the steel base in citric-acid solution for experimental packs of blackcurrants, sweet white cherries, gooseberries, loganberries, yellow Pershore plums and raspberries in double-lacquered cans; the agreement was by no means exact, but was a general tendency.

(4) For the packs of blackcurrants, gooseberries, loganberries, Pershore plums, raspberries and strawberries in double-lacquered cans here studied, the rate of formation of hydrogen-swells was significantly less for cans made from steel bases higher in copper, and therefore lower in phosphorus; for the packs of blackcurrants, gooseberries, loganberries and raspberries, the factor producing the better result was very probably the higher copper, while for those of Pershore plums and strawberries it was very probably the lower phosphorus. For a similar pack of sweet white cherries, the copper and phosphorus contents were immaterial. For all the packs, the sulphur content was immaterial.

(5) Since fruits are themselves variable, it is not possible to *predict with certainty* that the results given in (4) will apply to *any* packs of these fruits; but since high-copper, low-phosphorus tinplate has been shown to be favourable in six out of seven packs of seven typical fruits, its general use *may be expected to be advantageous on the average of these fruits.*

(6) The *amount* of improvement to be expected from the use of high-copper (about 0·16–0·22%), low-phosphorus (about 0·03–0·045%) steel rather than unspecified material taken at random, is estimated, roughly but conservatively, at a doubling of the time during which the first 10% of any given pack may be expected to fail through hydrogen-swells, for those fruits for which steel-base composition appears to be significant (*see* (4)).

(7) The "artificial" corrosion rate of steel base in 2 and 0·5% citric-acid solutions, under conditions of free and of restricted access of air, respectively, is significantly less in the higher-copper, lower-phosphorus steels. Both factors may be operative. There is, however, no further fall in corrosion rate above 0·2% of copper, but indeed some evidence of a slight rise.

(8) On the evidence of this and previous work, it appears that about 0·2% of copper is the optimum value, from the fruit-acid corrosion and hydrogen-swell point of view; the phosphorus content should be as low as pack-rolling considerations allow. As

before, this applies (so far) only to the six fruits that give the significant results of (4).

(9) Correlation of corrosion rate in citric acid with corrosion potential in the same acid confirms the previous conclusion that different steels of the type under study have *approximately* similar cathodes, the differences being largely anodic; but the smaller cathodic differences are sometimes of importance. Cathodic efficiency for the reaction $2H^+ + 2\varepsilon \rightarrow H_2$ in citric acid appears to be inhibited by increase of sulphur and stimulated by increase of phosphorus content; preliminary observations indicate also that cementite may be a stimulator of importance. For any steel, the height in millivolts of the corrosion-potential/corrosion-rate point above the average logarithmic curve given by all these points is an indication of the cathodic efficiency, and is termed the " cathodic increment."

(10) For the packs of white cherries and gooseberries in double-lacquered cans here studied, the rate of formation of hydrogen-swells was significantly greater for cans made from steel bases showing higher cathodic increments; thus it is probable that such steel base is in general undesirable for such packs.

Acknowledgments.

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CORRESPONDENCE.

Mr. W. E. RHODES (Research Laboratories, Messrs. Chivers & Sons, Ltd., Histon, Cambridge) wrote that the work of the authors emphasised the very considerable differences in the rate of corrosion, by dilute solutions of citric acid, of the base plate of random samples of tinplate marketed in Great Britain at the present time. Variations in the composition of the base plate, particularly of the elements phosphorus and copper, were equally noteworthy, and the conclusion that they might be directly related to variations in the corrosion rate was fairly well established. It was of interest to note that the variation in the content of copper was of the same order as that of sulphur and phosphorus, indicating that in the process of steel ingot production there might be segregation of all three elements.

The conclusions drawn from the practical canning tests were of immediate interest to all canners of English fruits, and perhaps more especially to manufacturers of cans destined to be filled with English fruits.

In this Laboratory the writer and his colleagues had also collected a considerable amount of data corroborating the findings of the authors, and some of their results had been previously published.[1]

It was apparent, however, that a rapid and simple means of testing steel base was required which would accurately indicate the relative life of the canned product. Laboratory corrosion tests in fruit juices might provide the means, and it was noted that the authors had such experiments in hand.

Finally, one must congratulate them on the extremely lucid style in which the paper was written, and on the utilisation of the method of statistical analysis on a mass of detail which would otherwise have proved difficult to interpret.

AUTHORS' REPLY.

The AUTHORS replied that Mr. Rhodes' kind appreciation of the paper was especially welcome, coming as it did from one who had had great experience in the commercial canning of fruits similar to those dealt with in the paper; they were glad to note that he considered their results of immediate practical interest.

It was too early yet to say how far fruit-juice tests could give an accurate indication of the life of a can. The authors did not think, however, that with so many unavoidable variable factors other than the steel base (such as variations in the tin, tin-iron compound, and lacquer layers in the tinplate, in the fabrication,

[1] W. E. Rhodes, *Journal of the Society of Chemical Industry*, 1938, vol. 57, p. 315.

filling and storage of the cans, and in the fruit itself), it would ever be possible to say, for example, "This steel base will give cans that, when packed with raspberries and stored at 25° C., will fail in 52 weeks." But it might well become possible to specify a lower limit of time below which no more than 1%, say, of the cans of a pack would fail, from a laboratory test on the steel base.

TRANSFORMATION OF AUSTENITE ON COOLING; MORPHOLOGY AND GENESIS OF THE AGGREGATES FORMED.

By H. JOLIVET (Ugine, France).

(Figs. 3 to 30 = Plates X. to XVII.)

Abstract.

An attempt is made to draw up a classification of the structures which form in low-alloy steels during the isothermal decomposition of the austenite in the upper ranges (Ar′) and the intermediate ranges (Ar″).

In addition to pearlite and troostite, the granular structures are described which have their origin in the lower portion of the upper range (Ar′), and for which there is no special designation.

On the other hand, the author adopts the term " bainite," which has already been suggested, to denominate the structures which appear in the Ar″ region, in preference to the terms acicular troostite, troosto-sorbite, troosto-martensite, &c.

It is also shown that the structures observed are typical of their temperature of formation. They are governed by the relative extent of the growth of the elements formed and of the formation of new elements in relation to the fundamental quantities N_g, N_c (rate of nucleation and rate of crystallisation) connected with the crystallisation of the constituents.

The analogies and specific characteristics of the structures in each of the regions are outlined, and an interpretation is given which suggests that the formation of the initial nuclei is due to two different constituents, *viz.*, cementite for Ar′, and supersaturated ferrite for Ar″.

Introduction.

The isothermal transformation of austenite has been studied by several research workers.[1] This has led to the differentiation of three ranges of transformation (upper, intermediate and lower), which, in the process of continuous cooling, are made manifest by the appearance of the critical points Ar′, Ar″ and Ar‴.[2] Each range is typified by a particular mode of transformation.

[1] Among the numerous researches on the subject, special mention may be made of those carried out by Bain and his collaborators (*see* Davenport and Bain, *American Institute of Mining and Metallurgical Engineers*, 1930, *Technical Publication No.* 348; Bain and Davenport, *Transactions of the American Society for Metals*, 1934, vol. 22, p. 670), and those of Wever and his collaborators (*see* Wever and Jellinghaus, *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1932, vol. 14, p. 85; 1933, vol. 15, p. 167. Wever and Lange, *ibid.*, 1932, vol. 14, p. 71; 1933, vol. 15, p. 179).

[2] These critical points have been studied, in particular, by Portevin and Chevenard (*Journal of the Iron and Steel Institute*, 1921, No. II., p. 117; *Comptes rendus*, 1921, vol. 172, p. 1490).

In the scale of temperature, these ranges are more or less definitely separated by zones of relative stability of the austenite.

Their presence has been revealed in a certain number of alloy steels containing nickel, chromium and molybdenum; and since they slow down the rate of decomposition, these elements have made it easier to analyse the phenomena.

On the other hand, the study of other compositions, and of plain carbon steels in particular, has revealed the presence of only two

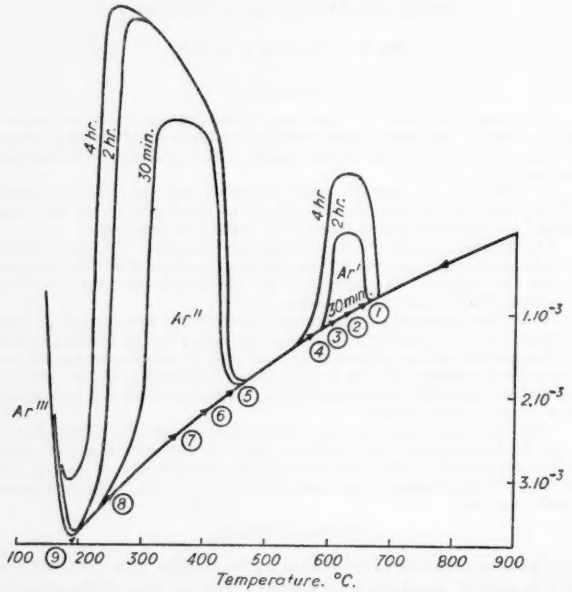

FIG. 1.—Isothermal Transformation of Austenite (Steel *A*). Magnitude of the anomaly revealed by the Chevenard dilatometer. The structures corresponding to the points indicated are illustrated in Fig. 3.

distinct ranges of transformation, either because one of the modes of transformation does not appear in this case, or because it has been impossible to separate two of the regions experimentally. A recent paper on the subject seems to indicate that this is the most probable hypothesis.[1]

The structures which originate either in the course of continuous

[1] The experimental methods and the results obtained are described by Wever and Hänsel, *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1937, vol. 19, p. 199, and Wever and Rose, *ibid.*, 1937, vol. 19, p. 289.

cooling or during isothermal transformation have been described in a certain number of cases.

It sometimes appears rather difficult to define them and to refer them to the mode of transformation by which they originate; this explains why a survey of the literature of the subject gives the impression that a fairly large number of distinct types exists.

A systematic study of isothermal transformation carried out on a sufficient number of low-alloy steels does actually lead to the conclusion that the structures observed can be reduced to a few types which can be produced in each of the compositions, provided the conditions of transformation are suitable. Certain types of structure are regularly noted in certain compositions, whereas others are rarely found; this is mainly due to the fact that the conditions under which the latter originate are seldom realised in practice. Thus there are certain structures, such as the Ar′ structures (pearlite and troostite) in steels containing 7–10% of manganese,[1] and the Ar″ structures (bainite) in steels containing 7–10% of nickel which can only be revealed by extremely slow cooling. These latter structures were observed by Portevin in 1911, but it was impossible to interpret them at the time.

By way of example, Figs. 1 and 2 show the results obtained for two steels, *A* and *B*, of the following chemical composition :

	Carbon. %	Manganese. %	Nickel. %	Chromium. %	Molybdenum. %
Steel *A*	0·6$_5$	0·4	2·7$_5$	0·7$_5$	0·6
„ *B*	0·7$_5$	0·7	...	1	0·6

These curves show the variations in the amplitude of the anomaly on dilatation curves obtained by means of a Chevenard differential dilatometer, when the samples, after being heated to 900° C., were quenched in metal baths at the different temperatures shown and allowed to transform isothermally. They bring out the three regions of transformation mentioned above, separated by clearly-defined zones of stability.

Figs. 3 and 4 show the appearance of some of the structures obtained in these samples which had been quenched in water at intervals during the isothermal transformation. These structures, which will be described later, are obviously similar for the two steels selected as examples.

It should be noted that one essential difficulty associated with a study of the products of decomposition obtained by continuous cooling has been eliminated here, *viz.*, the variation with the change of temperature of the types of structure which form.

By studying the isothermal transformation, it is possible to follow the origin and development of the decomposition structures at a given temperature, either in the absence of any previous transformation or after initial transformation of a fraction of the austenite at one or more other temperatures. Such tests of fractional iso-

[1] Portevin, *Comptes rendus*, 1917, vol. 165, p. 62.

thermal transformation were carried out at various rising or falling temperatures in the upper and intermediate regions. In this way, a succession of clearly differentiated structures, typical of the different testing temperatures, are made to form in the austenite, independently of the extent and the conditions of previous partial transformations.

The structures thus obtained, starting from austenite unstable under conditions far removed from equilibrium, are therefore essentially *typical* of the temperature of formation for a given composition.

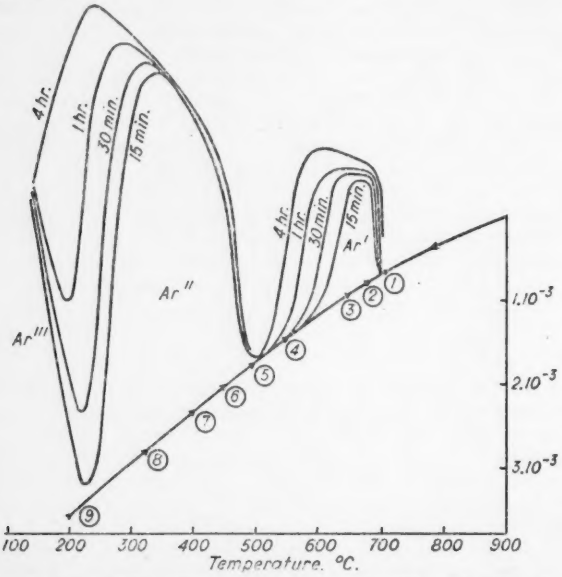

FIG. 2.—Isothermal Transformation of Austenite (Steel *B*). Magnitude of the anomaly revealed by the Chevenard dilatometer. The structures corresponding to the points indicated are illustrated in Fig. 4.

The study of isothermal transformation thus assumes a practical significance, owing to the fact that the nature of the products of transformation depends, at every moment in the process of continuous cooling, on the actual conditions (composition, temperature) in the residual austenite, the preliminary decomposition product of part of the austenite in the Ar′ or Ar″ ranges acting initially as transformation centres for the new structure.

Whereas the initial purpose was to be free from the temperature variations which, in the continuous cooling prevailing in practice, take place according to a law which is arbitrarily or empirically

fixed, the results may, owing to this absence of heredity, be extended to varied conditions of cooling starting from elementary transformations at each temperature.[1]

An attempt will now be made to outline the morphology and mode of development of the structures which are typical of the upper and intermediate ranges, the examination being confined to the case of eutectoid steels of different compositions.

Although these ranges are generally separated by a zone in which the austenite is relatively stable, they may sometimes interpenetrate, so that the structures to which they give rise may originate consecutively or simultaneously at the same temperature. In the latter case, certain structures which are usually observed in one of the ranges may not appear, since the conditions which govern their formation are suppressed by the development of the other mode of transformation. At the same time, however, each range is essentially characterised by the fact that the variations in the types of structure formed, in terms of temperature, are continuous. This continuity is due to the process of transformation being the same throughout the region. It is associated with the variations in the laws of the kinetics of transformation with the temperature.

It will be seen, then, that any divisions or distinctions which may be made with a view to classification are essentially artificial in character.

A.—Upper Range (Ar′).

The products of decomposition in this region may be divided into two groups, *viz.*, (*a*) lamellar group, and (*b*) granular group.

(*a*) *Lamellar Group.*

(1) *Morphology.*

The structures which originate at the highest temperatures, just below the critical point Ac_1, and approaching the maximum speed of transformation, usually have a lamellar structure or at any rate they have this structure at the moment they appear.

A distinction has long been made between pearlite and troostite, but it is now agreed that they are two varieties of the same aggregate (ferrite–cementite) possessing slightly different features and, in particular, a difference in the dimensions of the elements.

[1] This extension has not previously been touched on to any extent. Going on the simplified assumptions—sufficient in actual practice, in a certain number of cases—that the residual austenite maintains its initial composition, *i.e.*, that the aggregate formed has the same composition as the parent austenite, and that the nucleation is not essentially modified by the previous transformations—a knowledge of the laws governing the kinetics of isothermal transformation would enable the kinetics of transformation during the continuous coolings which prevail in practice to be treated mathematically. An attempt of this kind has been made for the initial induction period (Scheil, *Archiv für das Eisenhüttenwesen*, 1935, vol. 8, p. 565).

Pearlite.—Several writers [1] have described the characteristics of the lamellar pearlite which originates at the highest temperatures. Micrographic examination shows that, when its structure is most perfect, it is made up of alternate lamellæ of cementite and ferrite which are almost plane and are arranged in consecutive layers.

A lamellar group of this kind has frequently been termed a " pearlite grain." The essential features of a grain of this kind are that (*a*) the ferrite lamellæ, and (*b*) the cementite lamellæ have all approximately the same orientation and the same thickness. The grains therefore appear in the microsections (Fig. 5) in the form of regions for which the apparent thickness of the lamellæ, which are sensibly rectilinear and parallel, is a function of the true interlamellar distance Δ_0 and of the incidence of the secant plane ω.[2]

The possible relations between the directions of lamellæ of the pearlite " grains " and the crystallographic planes of the parent austenite have been mentioned on several occasions.

Assuming that the number of possible directions in the same austenitic grain is limited,[3] the directions of the lamellæ—provided that they are almost plane and parallel in form—may be governed by a group of crystallographic planes of the austenite.

Although this seems to be the most likely interpretation, it has not yet been confirmed by experiment. If it be correct, then we should have to admit that one of the two constituents—ferrite or cementite—the deposition of which governs the formation of the pearlite, has a higher speed of crystallisation along the directions of the privileged planes.

The relations which may hold between the crystallographic orientation of the cementite and the ferrite of the lamellæ, as well as between their respective orientations and that of the parent austenite, have not yet been elucidated. It should be emphasised, however, that these orientations are not necessarily related to the direction of the lamellæ, nor to their external form. The only point which does seem certain is that the ferrite lamellæ have the same orientation in the same " grain."

It is probable—but less certain—that the same applies to the

[1] Besides the fundamental work of Sorby (*Journal of the Iron and Steel Institute*, 1886, No. I., p. 140 and 1887, No. I., p. 255), the reader may also consult Howe and Levy (*Journal of the Iron and Steel Institute*, 1916, No. I., p. 210); Belaiew (*Journal of the Iron and Steel Institute*, 1922, No. I., p. 201); and Carpenter and Robertson (*Journal of the Iron and Steel Institute*, 1932, No. I., p. 309).

[2] Belaiew (*Journal of the Iron and Steel Institute*, 1931, No. II., p. 195) suggests defining each pearlite by its interlamellar distance Δ_0.

[3] Belaiew notes that the number of these directions does not exceed 12. On the other hand, he suggests the hypothesis that the cementite lamellæ are deposited parallel to one of the crystallographic planes of the ferrite. From this he deduces that this plane is probably the prismatic plane (210), but there seems to be no justification for this inference.

cementite lamellæ.[1] However, no connection has been established between the orientation common to the ferrite lamellæ and that common to the cementite lamellæ.

Mehl [2] attempted to study the relations between the orientations of the ferrite and the parent austenite, and his researches led him to conclude that there is a probable connection between them : The (112) planes of the ferrite are apparently parallel to the (110) planes of the austenite. He observed that this relation is totally different from that which holds between the orientations of the austenite and of the " acicular " ferrite showing a Widmannstätten pattern [3] and which is mentioned farther on. This fact leads him to suppose that the mode of deposition of the ferrite is different in the two cases.

The hypothesis propounded below, *viz.*, that a deposition of cementite originates the formation of the pearlite, agrees with the above findings, the orientation of the ferrite being, in this particular case, only indirectly related to the orientation of the parent austenite.

Furthermore, there are cases—fairly rare, it is true—where the pearlite exhibits different characteristics and consists of lamellæ radiating from a centre. These features are usually met with in the structures formed at lower temperatures.

Troostite.—When the temperature of formation drops, the pearlite becomes finer and finer, which means that the interlamellar distance decreases continuously (Fig. 6). At the same time, this pearlite is slightly modified in its characteristics, and becomes the constituent *troostite* which has frequently been described.[4]

After being more or less inaccurately defined, troostite is now usually regarded as being a very fine pearlite, the interlamellar distance of which has become too small to enable the lamellar character to be detected at low magnifications.[5] Since troostite is

[1] The common orientation of the ferrite lamellæ in pearlite is mainly based on the absence of crystalline boundaries at the fortuitous contacts between lamellæ, and on the etching figures (Belaiew, *Journal of the Iron and Steel Institute*, 1922, No.I., p. 201). The identity of the end cleavage of the cementite lamellæ when polished favours identity of orientation.

[2] *Cf.* Mehl and Smith, *American Institute of Mining and Metallurgical Engineers, Technical Publication No.* 566, *Metals Technology*, 1934, vol. 1, Sept.

[3] *Cf.* Mehl and Smith, *American Institute of Mining and Metallurgical Engineers, Technical Publication No.* 521, *Metals Technology*, 1934, vol. 1, Jan.

[4] Among the numerous papers dealing with the internal structure of troostite, the following may be consulted : Le Chatelier, *Revue de Métallurgie, Mémoires*, 1908, vol. 5, p. 640 ; Benedicks, *Journal of the Iron and Steel Institute*, 1908, No. II., p. 153 ; Lucas, *Proceedings of the World Engineering Congress, Tokio*, 1929, pp. 34–69 ; Schrader, *Stahl und Eisen*, 1924, vol. 44, p. 309 ; Robertson, *Journal of the Iron and Steel Institute*, 1929, No. I., p. 391 ; Belaiew, *Journal of the Iron and Steel Institute*, 1931, No. II., p. 195.

[5] The partial isothermal transformations of austenite at rising or falling temperatures do actually seem to show that the value Δ_0 is characteristic of the temperature of transformation.

Belaiew suggests that the whole of the lamellar group be defined by the values of the true interlamellar space Δ_0. Values of 300–350 $\mu\mu$ would corre-

frequently found after the partial transformation of austenite (Fig. 7) its nodular growth has received more attention than that of pearlite. Its nodules present a structure radiating from a centre and they often appear as if formed of a series of zones, in each of which the lamellæ are either parallel (as in pearlite) or radiate from the centre of the nodule.[1]

As far as it is possible to analyse such structures, the radial characteristic of the lamellæ would appear to occur particularly frequently at the lowest temperatures of formation, and near the centre of the nodules, whereas at their periphery this structure tends to be replaced by zones of parallel lamellæ. If this be so, troostite is probably made up of lamellæ radiating from a centre—at any rate, when it first forms and in its most typical development.

(2) *Mode of Development.*

Pearlite, like troostite, develops from a limited number of centres, each centre giving rise to a transformed region of convex surface, the extent of which increases with time.

Pearlite.—This surface usually includes small number of zones in which the alternate lamellæ are roughly parallel to a given direction.[2]

A group of this kind is nodular in general appearance, with an irregular convex contour. When development is fairly advanced, it is sometimes rather difficult to locate the centre from which the different zones originated. When such identification is possible, however (Fig. 9), this centre would appear to have been, at the outset, the seat of a crystallisation of cementite from which a limited number of radial lamellæ have developed.[3] This radial development of pearlite occurs only in fairly rare cases when crystallisation is relatively rapid as compared with the rate of formation of new lamellæ.

Generally speaking, the preferential development of certain cementite lamellæ along favoured directions involves the formation of fresh zones of parallel lamellæ.

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spond to pearlite, 250 to a fine pearlite, and approximately $\mu\mu$ 100 to troostite (*Transactions of the American Society for Metals*, 1936, vol. 24, p. 255).

The pearlites formed by continuous cooling would thus correspond to a certain Δ_9 range.

[1] These two types of structure, *viz.*, parallel lamellæ and radial lamellæ, had previously been detected in pearlite by Carpenter and Robertson (*Journal of the Iron and Steel Institute*, 1932, No. I., p. 309), who observed that the radial lamellar structure became more frequent with increase in the speed of cooling. The findings of the present author confirm and complete Carpenter and Robertson's observations.

[2] The lamellæ are almost plane. However, a fairly large number of local irregularities is observed, which may involve not only one lamella but an entire group. Some of these aspects (undulations) may sometimes have a secondary origin, such as the plastic deformation of the lamellar group.

[3] The formation of these lamellæ involves, at the same time, the transformation of the austenitic matrix into ferrite.

Actually, the mechanism of the formation of these zones has not yet been investigated satisfactorily; the most likely hypothesis to account for the cause of this distribution would appear to be that the crystallisation of one cementite lamella may involve the indirect formation of an adjacent ferrite lamella, which itself governs the formation of another parallel lamella of cementite, and so on, thus giving rise to a succession of elementary lamellæ exhibiting definite crystallographic relationships among themselves and with the parent austenite.

The development of the zones appears to be due to a double process. By the mechanism just described, fresh elementary lamellæ of very short length are developed laterally, while at the same time the lamellæ of cementite and ferrite already formed simultaneously develop endwise along their initial direction (Fig. 11). This may account for the convexity of the front of development, the earliest lamellæ being also the most developed. A few rare examples may be mentioned of cases where development took place substantially by the endwise growth of a limited number of parallel lamellæ, with the result that the nodular form is replaced by formations of acicular appearance.

The formation of fresh lateral lamellæ, which grow in their turn, would therefore be essentially due to a process of segregation in the austenite, whereas the endwise development of the lamellæ would take place without any appreciable modification of the composition of the austenite in the vicinity of the plane of development,[1] owing to the simultaneous crystallisation of the cementite and ferrite. In no instance, as a matter of fact, has the development been observed, beyond this plane, of isolated lamellæ of ferrite or cementite in the austenite such as is the case for other structures.

Briefly, and adopting the above interpretation, we are led to the following conclusions :

(1) The crystallisation of the cementite gives rise to centres of pearlitic transformation, the development of which initially radiates from the centre.

(2) Since the cementite tends to crystallise preferably along a limited number of favoured directions of the parent austenite, this involves the formation of zones of parallel lamellæ.

(3) The formation of fresh lamellæ is due to a phenomenon of segregation in the austenite, whereas in the subsequent development of these lamellæ the crystallisation of the two constituents is practically simultaneous.

The above interpretation, suggested by the observation of numerous lamellar structures in process of growth, calls for more complete experimental verification, which seems difficult to achieve.

[1] Neither of the two processes excludes the other, as Mehl (American Society for Metals, October, 1938, Preprint) assumed. On the contrary, they are contemporary and relatively independent.

Troostite.—It is seldom that a lamellar structure radiating from a centre (rosette structure) is observed at the highest temperatures, owing to the formation of zones of parallel lamellæ of pearlite the extension of which restricts the growth of the radial lamellæ; but this structure is more frequently observed, at least in the vicinity of the centres, when the temperature of transformation falls. At the same time, the external shape becomes more definitely nodular (Fig. 12).

Each nodule consists at first of divergent lamellæ growing out from the centre. When the space between these lamellæ increases, other lamellæ will be seen to appear at a certain distance from the centre, and they assume (*a*) an intermediate direction or (*b*) a direction parallel to one of the initial lamellæ.

In case (*b*), there may be formed, at a certain stage in the development, narrow zones of parallel lamellæ between radiating lamellæ.

It is these mixed nodules which give rise to the " fan " structure that has sometimes been described, in which the different zones of parallel lamellae are arranged regularly about the centre and bounded by radial lamellæ (Fig. 13).

The growth of these zones is usually limited by the meeting of lamellæ coming from different directions belonging to the same nodule or to adjoining nodules. As a matter of fact, it is seldom that two different orientations of the cementite lamellæ are present at the same time in the same zone.[1]

Another limitation to the development of the zones is the existence of the boundaries of the austenitic grains.

Mention has often been made of the fact that the centres of transformation preferably originate at the austenite grain boundaries.[2]

Although the nodules are often confined to a single grain, one particular centre may give rise to a nodule which involves several grains, especially when the radiating structure has reached a certain stage of development. However, the case is never met with where any one zone of parallel lamellæ is not entirely localised in a single grain of austenite and is not arrested in its growth by the boundaries of this grain.[3]

(*b*) *Granular Group.*

The structural features now to be studied are definitely connected with the upper range of transformation, but have not previously been described to any extent. This is probably due to the fact that

[1] There are, however, cases where the cementite lamellæ assume several directions at the same time in a ferrite zone having a single orientation. These structures recall the Widmannstätten structure, and suggest that certain relations hold between the directions thus observed.

[2] This is not exclusively the case, as has often been assumed. When nucleation is active, centres may originate at other points, particularly in the vicinity of inclusions.

[3] This observation is consistent with the hypothesis that the directions of the lamellæ are related to the crystallographic planes of austenite.

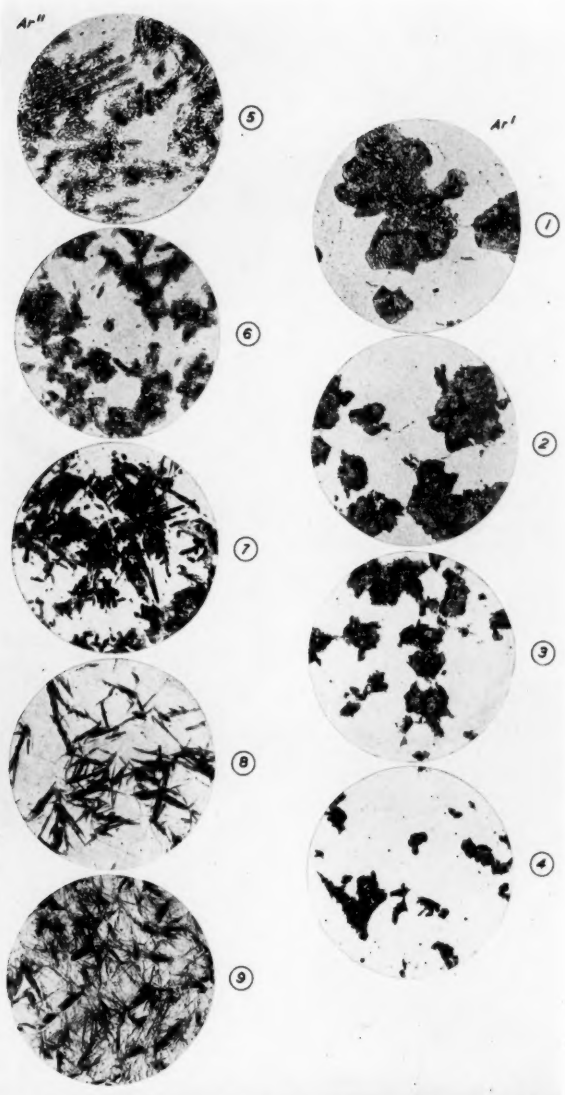

FIG. 3.—Isothermal Transformation of Austenite (Steel *A*). Structures corresponding to the points indicated on Fig. 1.

[*Jolivet.*

[*To face p.* 104 P.

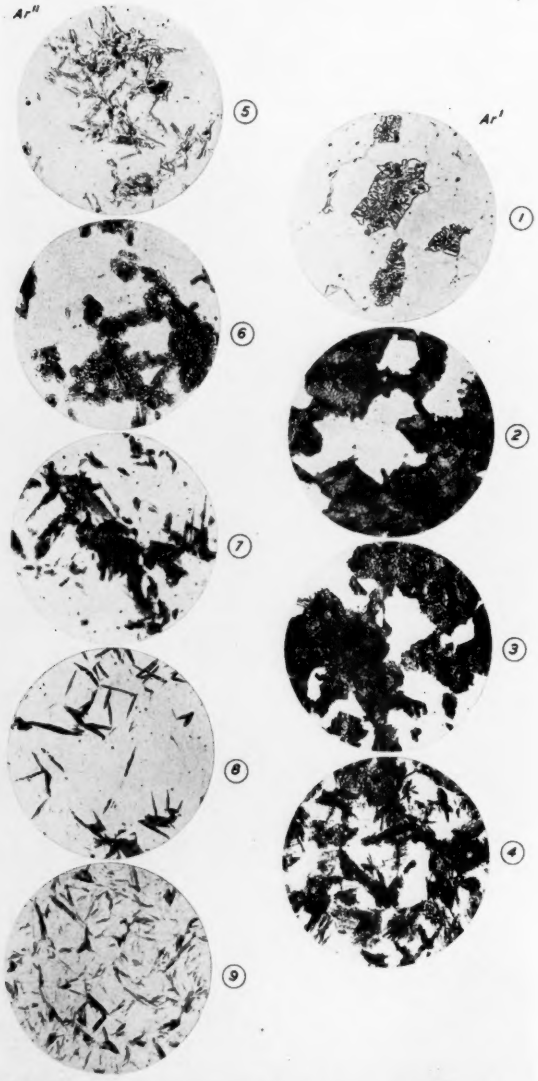

FIG. 4.—Isothermal Transformation of Austenite (Steel *B*). Structures corresponding to the points indicated on Fig. 2.

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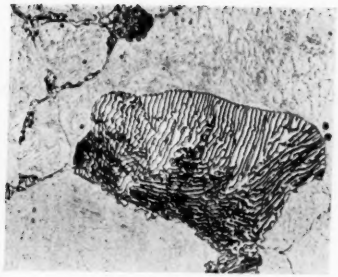

FIG. 5.—Coarse Lamellar Pearlite. Steel *A*, 650° C. for 135 min. × 1100.

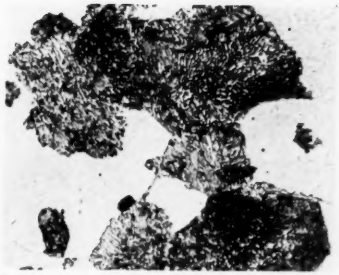

FIG. 6.—Fine Lamellar Pearlite. Steel *A*, 625° C. for 100 min. × 1100.

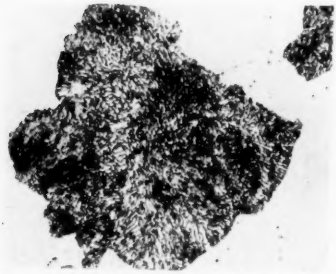

FIG. 7.—Nodular Troostite. Steel *B*, 680° C. for 10 min. (Note a granular region on the left.) × 1100.

FIG. 8.—Nodular Troostite. Steel *A*, 600° C. for 135 min. (Mixed lamellar-granular structure.) × 1100.

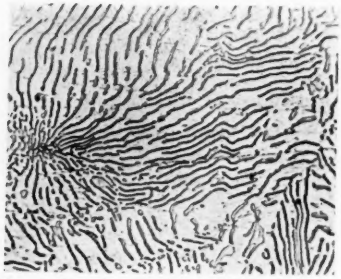

FIG. 9.—Lamellar Pearlite, radial development. Steel *B*, 720° C. for 24 hr. (*See* also Fig. 29.) × 1100.

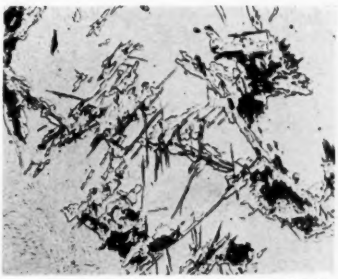

FIG. 10.—Acicular Cementite (Ar′) and Ferrite (Ar″). Steel *B*, 500° C. for 240 min. × 1100.

(Micrographs reduced to four-fifths linear in reproduction.)

[*Jolivet.*

FIG. 11.—Lamellar Pearlite, diagrammatic.

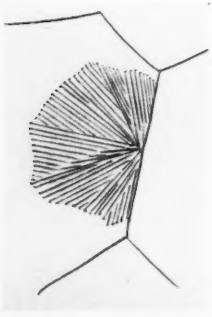

FIG. 12.—Troostite, diagrammatic.

FIG. 13.—Troostite, diagrammatic.

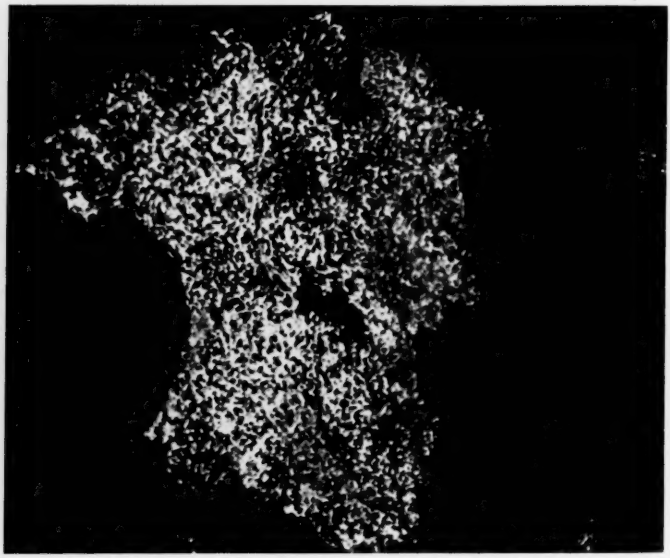

FIG. 14.—Granular Structure, nodular form (coloured by etching). Steel *A*, 600° C. for 135 min. × 2000.

(Fig. 14 reduced to four-fifths linear in reproduction.)

[*Jolivet.*

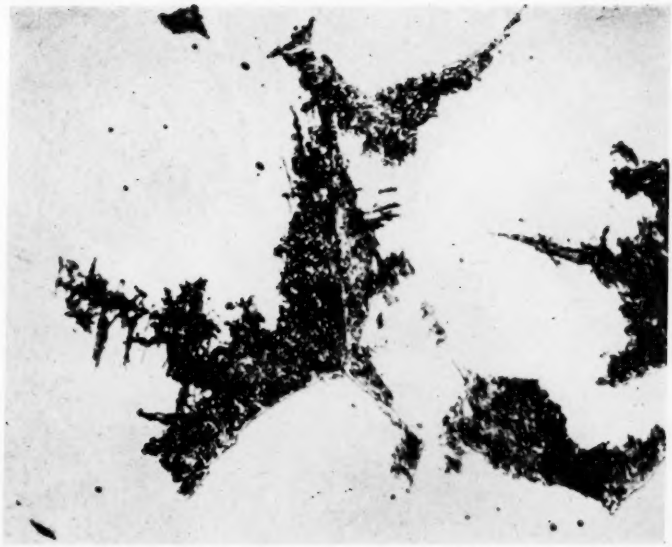

FIG. 15.—Granular Structure, arborescent form. Steel *A*, 550° C. for 240 min. × 2000.

FIG. 16.—Granular Structure, arborescent form. Steel *B*, 550° C. for 180 min. × 2000.

(Micrographs reduced to four-fifths linear in reproduction.)

[*Jolivet.*

FIG. 17.—Granular Structure, nodular form, diagrammatic.

FIG. 18.—Granular Structure, arborescent form, diagrammatic.

FIG. 19.—Granular Structure and acicular formations, diagrammatic.

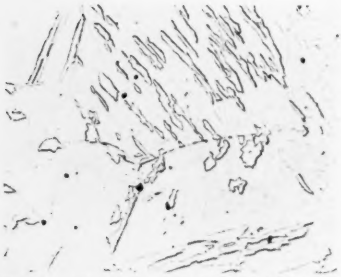

FIG. 20.—Acicular Ferrite. Steel *B*2, 550° C. for 60 min. × 1100.

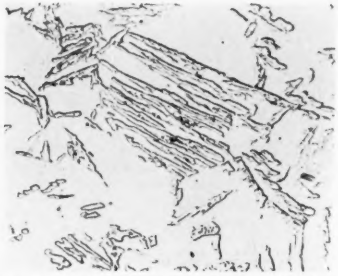

FIG. 21.—Acicular Ferrite. Steel *A*2, 470° C. for 2 min. × 1100.

FIG. 22.—Upper Bainite. Steel *A*, 465° C. for 240 min. × 1100.

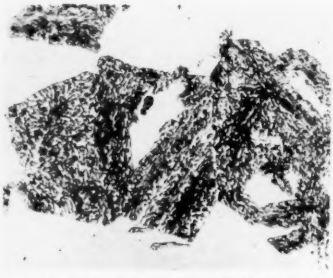

FIG. 23.—Upper Bainite. Steel *A*, 400° C. for 15 min. × 1100.

(Figs. 20 to 23 reduced to four-fifths linear in reproduction.)

Jolivet.

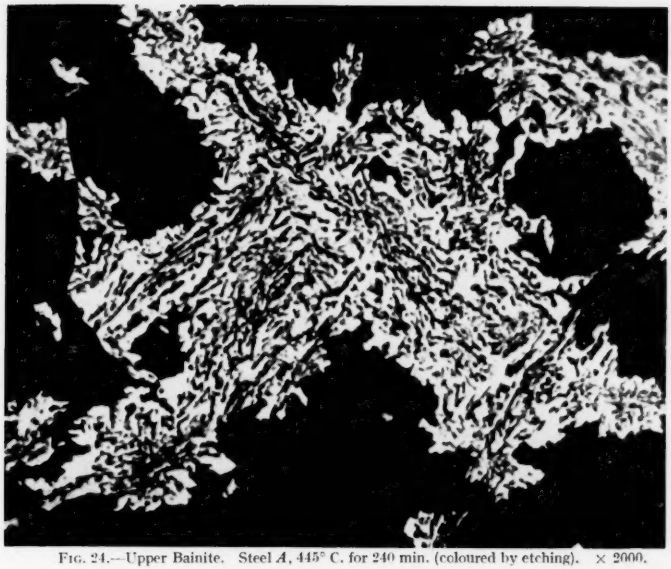

FIG. 24.—Upper Bainite. Steel *A*, 445° C. for 240 min. (coloured by etching). × 2000.

FIG. 25.—Lower Bainite. Steel *B*, 400° C. for 5 min. × 2000.

(Micrographs reduced to four-fifths linear in reproduction.)

[*Jolivet.*

FIG. 26.—Lower Bainite. Steel *A*, 350° C. for 20 min. × 1100.

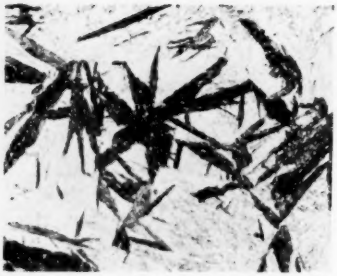

FIG. 27.—Lower Bainite. Steel *A*, 300° C. for 30 min. × 1100.

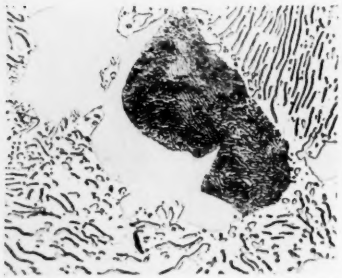

FIG. 28.—Partial Transformation, Steel *B*. (1) Coarse pearlite; 720° C. for 360 min. (2) Fine pearlite; 700° C. for 40 min. × 1100.

FIG. 29.—Partial Transformation, Steel *B*. (1) Coarse pearlite; 720° C. for 360 min. (2) Granular structure; 600° C. for 30 min. × 1100.

FIG. 30.—Partial Transformation, Steel *B*. (1) Granular structure (coalesced); 600° C. for 20 min. (2) Coarse pearlite; 720° C. for 360 min. × 1100.

(Micrographs reduced to four-fifths linear in reproduction.)

[*Jolivet.*

[*To face p.* 105 P.

they have seldom been detected in the process of their development. Moreover, they appear separately and clearly only in little-used eutectoid or hypereutectoid steels other than the plain carbon steels (nickel-chromium or chromium-molybdenum steels, for example).

On the other hand, the cases in which they have been seen have generally led to doubtful interpretations of their origin. They have apparently sometimes been related to the products of decomposition, at lower temperature, of the bainite or acicular-troostite type which will be described later.

(1) *Morphology.*

Nodular Form.—Below the temperature corresponding to the maximum speed of transformation the internal structure of the nodules formed is apparently modified (Fig. 8). At medium magnifications this structure is difficult to analyse under the microscope; it is observed, however, that the surface of the nodules, or at least certain regions, are more easily coloured by the etching reagents. Microscopic examination at the highest powers shows, in these regions, the existence of a structure formed of very numerous grains which assume the shape of rods or globules on a ground-mass slightly coloured by acid-etching. The results obtained on etching with alkaline ferricyanide (Fig. 14) make it seem probable that these are grains of cementite.[1]

These granular cementite formations develop at the higher temperature with convex contours (Fig. 17)—nodules which form a transition to the finely lamellar troostite nodules.[2]

Arborescent Form.—When the transformation temperature is lower, the structure of these nodules becomes finer and the ground-mass more colourable by the reagents.[3] At the same time, the convex forms are replaced by formations orientated with re-entrant angles (Fig. 15).

Being usually still restricted by the boundaries of the austenite grains, the transformed zones develop along very few preferred directions. These directions seem to be related to the crystallographic directions of the parent austenite (Fig. 18).

The arborescent appearance of these formations recalls the dendrites observed during solidification. At still lower temperatures

[1] When the samples are held for some time at a higher temperature, after a partial transformation which gives rise to a structure of this type, coalescence of the cementite very quickly results. The granular appearance is then very clearly brought out; the globules can be detected more easily, whereas the ground-mass is no longer coloured by the etching reagents (Fig. 30). Moreover, the coalescence of these granular aggregates is much more rapid than the coalescence of the lamellar pearlite which forms at the highest temperatures.

[2] The transition is continuous, and mixed nodules are frequently observed.

[3] This coloration by the reagents may, for instance, be accounted for by the presence in the ferrite of cementite in a very fine state of division. Only the coarsest elements would be resolved.

of formation (Fig. 16), the acicular extensions which develop in the favoured directions increase in extent, and give rise to groups of needles arranged in structures of the Widmannstätten type (Fig. 19).

Lastly, isolated needles with the characteristics of cementite are formed, in a Widmannstätten pattern, and frequently interfere with the products of transformation in the intermediate range (Fig. 10). When the granular zones practically cease to form, these needles are the only indications of transformation having taken place in the upper range.[1]

B.—Intermediate Range (Ar'').

The products of decomposition which form in this range have not been so exhaustively investigated as those which form in the upper range. Up to the last few years there has been a great deal of confusion concerning their nomenclature, and the term " acicular troostite " is the one which has most often been applied to them.

Ever since research, based on micrographic examination, was carried out on the isothermal transformation of austenite, it has appeared necessary to select a special designation which will avoid all confusion with the aggregates observed in the upper range.

Following on the researches of Bain and his collaborators, the name " bainite " has been suggested to designate the group of structures which originate in this way.[2]

This term would therefore cover a whole series of structures derived from a single mode of transformation, which are modified in a continuous manner as the temperature of formation changes.[3]

Obviously, the extreme types differ fairly considerably from each other, for which reason certain writers have separated them into " upper bainite " and " lower bainite " for the sake of clarity. This distinction will be adopted by the present author, although it is perhaps rather artificial in character, like the distinction, for example, which differentiates pearlite from troostite, or, more precisely still,

[1] When deposited alone in the austenite grains, the acicular cementite—or, more precisely, the lamellar cementite, for there are really lamellæ—grows, like the ferrite, along definite directions (Widmannstätten structure). Without being strictly plane, the lamellæ are complex, being formed of a group of separate elements. It has not been possible to determine exactly the plane of precipitation in the austenite, nor the orientation of the cementite (Mehl, Barrett and Smith, *Transactions of the American Institute of Mining and Metallurgical Engineers, Iron and Steel Division*, 1933, vol. 105, p. 225).

There is a certain dispersion around average directions, which are, however, different from the octahedron.

[2] J. R. Vilella and L. R. Cooper, *Metals and Alloys*, 1937, vol. 8, Jan., p. 22; 1938, vol. 9, Sept., p. 223.

[3] Micrographs of characteristic structures of this type of decomposition at the upper and lower limits of the range have been published by Vilella, Guellich and Bain (*Transactions of the American Society for Metals*, 1936, vol. 24, p. 225). Their Fig. 22, in particular, demonstrates the granular structure which will be described later.

the lamellar structures from the granular structures in the upper region.

Referring only to the eutectoid steels, the structures observed below the zone of relative stability of the austenite separating the two ranges (Ar′ and Ar″) may therefore be described as follows :

(*a*) Acicular ferrite.
(*b*) Upper bainite.
(*c*) Lower bainite.

(*a*) *Acicular Ferrite.*—The constituent originating at the highest temperatures of this range manifests itself in the form of plates, the sections of which appear as needles, originally isolated (Fig. 20). When their dimensions are fairly considerable, these needles sometimes include globules or filaments of a constituent exhibiting the characteristics of cementite. More often this cementite is localised at the periphery, and only a marginal deposit is observed.

In any one austenitic grain, the development of the transformed regions takes place along a small number of preferred directions. They are usually very elongated in these directions, hence their acicular appearance. This particular aspect may, however, be masked when they attain appreciable transverse dimensions. When they increase in number, a series of definitely separated parallel needles is observed in a particular grain (Fig. 21).

These needles exhibit all the characteristics of ferrite. Their directions are related to the crystalline orientation of the austenitic grain, thus giving the well-known appearance of the Widmannstätten structure.[1]

Further, X-ray examination leads to the conclusion that an α lattice is present.[2]

(*b*) *Upper Bainite.*—At lower temperatures of formation, the needles no longer appear in groups of separate individuals (acicular ferrite), but groups of parallel and contiguous needles originate, to which the name " upper bainite " has been given.

The needles which form, acting as centres of transformation, cause, while they are developing, the formation of other parallel needles separated only by a border of cementite. This results in

[1] Mehl (*Transactions of the American Institute of Mining and Metallurgical Engineers, Iron and Steel Division*, 1933, vol. 105, p. 215, and *American Institute of Mining and Metallurgical Engineers*, 1934, *Technical Publication* No. 521) has studied the crystallographic relations between these Widmannstätten deposits of ferrite and austenite in iron and in hypo-eutectoid carbon steels. The (110) planes of the ferrite are parallel to the (111) deposition planes of austenite. This relation is found in martensite, but differs, as has been seen, from that which is supposed to exist in pearlite. It would obviously be interesting to determine these relations in the case of the eutectoid steels.

[2] A few determinations made on a similar steel (carbon 0·5%, nickel 2·87%, chromium 0·7%) have shown that the separate phase exhibits the characteristics of ferrite observed in the annealed state. These determinations are due to the kindness of Professor Phragmén, to whom the author tenders his thanks.

transformed regions in which the cementite is distributed in films that are more or less ramified and vermiculate, but which retain the orientation of the initial needles [1] (Figs. 22 and 24).

When they are slightly developed, these zones retain an acicular appearance in their external form. Frequently limited by the boundaries of the austenitic grains, they often show, at certain points, secondary branches of different orientation, or interlace to give Widmannstätten figures.

When, on the other hand, these zones and their branches have developed considerably, they lose their orientated character, resulting in an aggregate without any well-defined structure which recalls pearlite in process of coalescence.

The structure increases in fineness as the temperature of formation falls (Fig. 23), but the zones go on developing from a limited number of centres, either by the growth of the needles already formed or by the formation of fresh needles.

(*c*) *Lower Bainite.*—From a certain temperature, again somewhere about that corresponding to the maximum rate of transformation, the appearance of the products is gradually modified (Figs. 25 and 26).

The transformed zones, of which the structure becomes so fine that it can no longer be resolved at medium magnifications, are more and more susceptible to coloration by the micrographic reagents (acid or colouring reagents).

At high magnifications, each of the needles appears to consist of a large number of elements, and on the ground-mass will be noted grains of a constituent which may be considerably coloured.

At the same time, as the temperature becomes lower, the acicular character of the product becomes more and more accentuated, the needles decreasing in size and their development having a more marked tendency to take place along a preferred direction (Fig. 27).

Although its mode of formation and of development is different, the aggregate thus formed at the lowest temperatures exhibits very considerable analogies with martensitic structures partially transformed by prolonged tempering at the same temperatures.

There is an additional complication due to the fact that, in certain cases, bainite continues to form below the martensite point.

Differentiation is therefore a very delicate matter, since bainite is not distinguishable from tempered martensite and the tempering of martensite already takes place at the temperature of formation. Indeed, differentiation is only possible when the martensite forms at a lower temperature and has not undergone tempering, in which case it reacts differently to the etching reagents. It is probably this same difficulty of identification which gave rise to the complex and ambiguous terminology which has been suggested for denominating these structures, *viz.*, troosto-martensite (Griffiths),

[1] There is a certain similarity of appearance between these structures and lamellar pearlite, but the distribution of the cementite is not so regular.

martensite-troostite (Davenport and Bain), troosto-sorbite (Kourbatoff), pseudo-martensite, &c.

C.—Characteristics and Analogies of the Structures Formed in the Upper (Pearlite) and Intermediate Regions.

Analogies.

Although the previous sections of this paper show that essential differences exist between the transformation of austenite in the upper (pearlite) and in the intermediate ranges, distinct resemblances are found.[1]

In both ranges, the transformation, proceeding from a limited number of centres, gives rise to transformed regions which spread by the growth of the elements already formed or by the formation of fresh elements. The relative importance of these factors is altered by the decrease of temperature in the same way for both types of transformation.

At the highest temperatures of each range, few elements are formed and are able to develop so as to form structures which are comparatively coarse, the modes of deposition and arrangement being, however, different in each case.

At lower temperatures, in the transformed areas the elements from which growth has taken place are more numerous. The structures formed, when development has proceeded to an appreciable extent, are of the same type, but become finer and finer.

In this way, the maximum rate of transformation is attained when the structure consists of a large number of elements, but when these have not grown to any appreciable extent. These latter structures are very difficult to analyse by micrography. The transformed regions are developed essentially by the formation of new elements, rather than by growth of the elements which have already formed.

As the temperature continues to fall, the appearance of these elements and, hence, the development of the zones are slowed down; and, instead of involving the entire mass, growth takes place at first only in preferred regions.

To continue with the example of the upper range, when the number of centres of initial transformation is small and their rate of growth slow, coarse structures with parallel elements will be observed (pearlite). Increase in the rate of growth favours the formation of radial structures, while at the same time the increase in the number of initial centres conduces to the formation of structures

[1] The analogies of structure, derived from analogies in the modes of transformation, are accompanied by analogies in the kinetics of transformation. This fact did not escape Mehl (American Society for Metals, Oct., 1938, Preprint), who considers it as surprising, because he assumes that the Ar″ transformation is derived from a process of the " martensitic " type.

of increasing fineness (troostite). Near to the maximum rate, the structures become granular and are formed from a very large number of elements, while the development, which was nodular at first, assumes an arborescent or acicular character.

The rate of nucleation (N_g) and the rate of crystallisation (N_c) must not be confused with the number of centres of transformation or the rate of growth of the transformed regions. The centres correspond to the appearance in the austenite of isolated nuclei of the constituent which is formed first (cementite or ferrite).

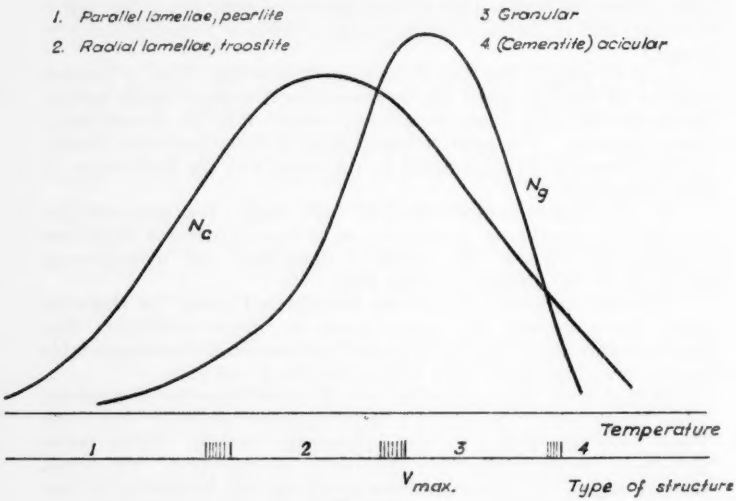

FIG. 31.

Further, in each nodule the structure is governed by the number of fresh nuclei which appear and their rate of growth.

It is difficult accurately to interpret the structures formed in terms of these quantities, but Fig. 31 represents a possible hypothesis.

Specific Characteristics.

Despite these analogies, the two ranges of transformation have a definite individuality.

An examination of the specific differences which characterise each range will show that the most satisfactory interpretation at present is the difference in the character of the element the formation of which originates transformation.

Although this transformation finally results, in every case, in ferrite-cementite aggregates, the constituent produced first, in the

form of nuclei, appears to be cementite in the upper region, and a supersaturated ferrite in the intermediate region.[1]

This interpretation is in agreement with a certain number of micrographic observations and views on the kinetics of the transformations. Thus, in the upper (pearlite) range the following are observed :

(*a*) Structures consisting of cementite lamellæ diverging from a single centre.
(*b*) Pseudo-Widmannstätten structures, due to the cementite.
(*c*) Cementite needles which develop alone in the austenite at the lowest temperatures.

On the other hand, when the carbon content rises up to the eutectoid point :

(*a*) The periods of induction, generally related to the conditions of nucleation, decrease.
(*b*) The rates of transformation, and the maximum rate in particular, increase.
(*c*) The difference between the temperature of transformation on heating and that of the maximum rate of isothermal transformation on cooling diminishes.

Similar observations may be applied to the intermediate region, such as :

(*a*) The formation of isolated plates of ferrite.[2]
(*b*) The Widmannstätten structure of the ferrite deposits.
(*c*) The precipitation, in this ferrite, of cementite which would no longer originate directly from the austenite.

In the same way, when the carbon content falls below that of the eutectoid the induction periods decrease and the speeds of transformation increase.

Conclusions.

The results obtained from the investigation of the isothermal transformation products of the austenite in the low-alloy steels may be interpreted as follows :

(1) In the upper range (Ar′) and the intermediate range (Ar″),

[1] This interpretation, already outlined by the author (Portevin and Jolivet, *Annales de l'Academie des Sciences Techniques à Varsovie* 1937, vol. 4, p. 177), has recently been taken up by Mehl (American Society for Metals, Oct., 1938, Preprint). That writer did not demonstrate the granular structures of the upper range, and attributed the " upper bainite " to this range of transformation.

[2] It has been objected that this deposit could not form in the eutectoid or hypereutectoid steels, in which this range could not exist. The author has shown (*Comptes rendus*, 1938, vol. 207, p. 1412) that the separation of ferrite can be observed even in this case, after hypereutectoid cementite is deposited under conditions removed from equilibrium.

transformation proceeds from a limited number of centres, either by the growth of elements already formed or by the formation of fresh elements. Since the modes of transformation are analogous in the two ranges, the differences observed in the structures cannot be explained in this way. Both are governed by the conditions of nucleation and crystallisation of the ferrite and the cementite in the austenite.[1] The difference is based on the element—cementite or ferrite—which originates the transformation.

The structures most frequently observed—which generally correspond to the rates of transformation near the maximum—are composed of parallel or radial lamellæ in the Ar′ region, and of Widmannstätten type in the Ar″ region, but neither structure is absolutely characteristic of either region.

Similarly, there is no characteristic mode of growth. The structures most frequently revealed, when the conditions are such that transformation remains incomplete, are nodular in the Ar′ zone, and acicular in the Ar″ zone. Neither is typical of any one region; they are to be related to the relative importance of the nucleation rate and crystallisation velocity of the initially deposited material and, in particular, to the preferential growth along certain directions of the γ lattice.

(2) The investigation of a certain number of alloy steels which contain small percentages of nickel, chromium and molybdenum shows that all the structures obtained by isothermal transformation of austenite exhibit the same features, and may be reduced to a few types. They are simply dependent upon the conditions existing at the time of formation.

It is sometimes rather difficult to identify the characteristics of the structures obtained after total transformation. The structures, as formed, are usually unstable, and may be modified by secondary phenomena, such as coalescence and graphitisation.

The formation of certain types of pearlite or bainite—at the highest temperatures—is so slow that coalescence takes place during the process of formation. This then results in aggregates in which the cementite is coalesced in zones of ferrite without any definite form.

(3) For each composition, the structures observed, governed by the rate of nucleation (N_g) and the rate of crystallisation (N_c), are characteristic of the temperature of formation.

The partial transformation of austenite leads to the formation of as many structures as there are temperatures at which the steels may have been held. When the change from one temperature to the next is abrupt, the change of structure is also discontinuous and not gradual (Figs. 28 to 30).

The zones already transformed act as centres of transformation for the new structure and at the same time fresh centres appear.

(4) There are many difficulties associated with the nomenclature

[1] They consequently depend on phenomena of diffusion in the austenite.

of these structures, which is based on arbitrary divisions, the variations of structure in each range being of a continuous character.

Except for certain very definite types, the features are difficult to analyse. If the structures are formed of ferrite-cementite aggregates, they are differentiated by the distribution of the constituents, or by the mode of growth of the transformed regions.

The lamellar structures exhibiting a nodular development (A_2') are the only ones that have been clearly differentiated.

Bain and his collaborators [1] have rightly observed that, in the products arising from the direct transformation of austenite, only lamellar pearlite is defined without ambiguity.

Although the term " troostite " has sometimes been applied to martensite decomposed by tempering, it is now reserved almost exclusively for defining lamellar structures having a nodular development and which differ from pearlite by their fineness and their radial orientation.

There is no term to define the granular structures of the lower part of the Ar′ range, whether their development be nodular or arborescent.

The structures which originate in the Ar″ range have here been termed " bainite "—a term suggested by certain writers and which has the merit of avoiding all confusion.

Although, in the author's opinion, the genesis of this constituent is the same throughout the Ar″ region, he has adopted the classifications " upper bainite " and " lower bainite " for the sake of convenience. This designation seems preferable to " acicular troostite " which the author himself adopted previously for defining the structures formed in this region.[2]

This nomenclature is further complicated by the secondary modifications of the structures formed, mainly by coalescence, which is particularly rapid in the upper temperature range. Certain types of pearlite or of bainite coalesce in this way in the process of formation. Others coalesce on reheating. The aggregate which then results can no longer be connected with the original structure. The terms " globular pearlite " or " granular pearlite " which have sometimes been applied to these structures ought therefore to be avoided, and it would be preferable to call them " coalesced structures."

In short, the difficulties of naming the aggregates which are formed when austenite decomposes are numerous, and have given rise to much controversy.[3]

(*a*) One of the difficulties is due to the artificial character of the distinctions thus made with a view to classification in a series which is actually continuous. Osmond wrote in 1909 : " The absence of

[1] Vilella, Guellich and Bain, *loc. cit.*, p. 225.

[2] Portevin and Jolivet, *loc. cit.*

[3] *See*, in particular, Osmond and Le Chatelier, *Revue de Métallurgie, Mémoires*, 1909, vol. 6, pp. 1183, 1188, and 1907, vol. 4, p. 1364.

discontinuity is clear. If we want to be logical, we should have to ask for the unconditional suppression of all the constituents. This view might be defended . . . Physicists might disapprove of the words used for defining the colours . . . but could we understand ourselves better in this way? "

(*b*) Another not less serious difficulty is the necessity for respecting established usage to a certain extent and for adhering to existing terms which, coined many years ago, have sometimes assumed a rather ambiguous significance since.

(*c*) Finally, the definition of the aggregates may be based on several criteria, which may be used concurrently or not to describe them. These criteria may refer to the conditions of formation (for example, nodular structure originating in the middle part of the Ar′ range), to the nature of the constituents (for example, supersaturated α solid solution), or, again, to the morphology of the products formed (say, lamellar structure consisting of parallel and alternate lamellæ of cementite and ferrite).

In conclusion, it might be well to follow the suggestion of Sauveur [1] and undertake, from these various standpoints, the revision of the terms at present used to designate the aggregates which result from the transformation of austenite.

[1] *Metal Progress*, 1938, vol. 34, July, p. 59.

ANTIMONY IN MILD STEEL.*

By B. JONES, D.Sc., F.I.C. (University College, Cardiff), and J. D. D. MORGAN, B.Sc. (Abadan, Iran).

(Figs. 7 to 30 = Plates XVIII. to XX.)

Synopsis.

The authors refer to the lack of information on the effects of certain elements on steel. Experiments are described in this paper on the effects of increasing the antimony content in a 0·17% carbon steel. A complete investigation was not attempted, but the influence of the element on some of the useful properties of the steel was examined. Twelve steels of basic electric origin and four high-frequency steels were tested. Antimony has practically no effect on the A_1 point, but progressively raises the A_3 temperature of steel owing to its stabilising effect on α-iron. The microstructures found have been correlated with the iron-antimony equilibrium diagram. Steels containing up to 0·69% of antimony can be hot-forged and hot-rolled, but with higher antimony contents the steels become increasingly red-short. Antimony has practically no effect on the tensile strength, while increasing amounts rapidly decrease the maximum stress to very low values. As with other elements in group Vb. of the Periodic Table forming γ loops with iron, such as phosphorus and arsenic, antimony embrittles steel, low notched-bar impact values being found in steel containing more than approximately 0·5% of the element. The influence of antimony on case-hardening processes has been examined. Small amounts of antimony were found to make steel slightly more susceptible to atmospheric corrosion and acid attack. Steels with increasing amounts of antimony become more resistant. Above 0·5% of antimony the steels resist attack to an increasing extent by 5% and 25% sulphuric acid at 25° C., and to a less degree by hydrochloric acid of the same strengths. Antimony-cemented steel is highly resistant to atmospheric and acid attack.

Introduction.

While the influence of the usual alloying elements in steel has been the subject of considerable investigation, owing to the industrial importance of the steels, it is considered that insufficient data are available about the effects of certain other elements, even on the useful properties of steel. The elements which have not been the subject of intensive study as constituents of steel are generally supposed to impart no practical benefit, the properties of such steels being generally anticipated from considerations of the atomic weight, the crystal structure and physical properties of the element, together with a comparison of the influence on steel of an element of analogous characteristics. It has long been considered, however,

* Received July 10, 1939.

that the effects of certain elements on steel should be known with a greater degree of exactitude, even when the imparted properties would be detrimental to the industrial value of the steel. The answer to such questions as "what percentage of the element may be present in a carbon steel before the mechanical properties are impaired?" or "what are the effects of small and large amounts of the element on the corrosion resistance of the steel?", &c., must remain a matter for speculation until research provides more precise information.

Such investigations are being carried out at University College, Cardiff, with the object of ascertaining the effects of certain elements on the properties of carbon steel. It was realised, however, that a consideration of all the factors involved in the influence of an element on steel would take a considerable time, and is, perhaps, beyond the scope of a private research, but, on the other hand, it was considered highly desirable that the effects of certain elements on the useful properties of even low-carbon steel should be found within a reasonable period of time.

This paper deals with the influence of varying amounts of antimony on some of the properties of a 0·17% carbon steel.

Antimony crystallises in the rhombohedral hexagonal system; its atomic weight is 121·76, and, together with nitrogen, phosphorus, arsenic and bismuth, it belongs to Group Vb. in the Periodic Table. An excellent treatise on X-ray studies of the binary system of iron with each of these elements has been published by Hägg.[12]

A search in the metallurgical literature showed that comparatively little has been published on the influence of antimony on iron and steel. The first reference to the subject was in Percy's "Metallurgy of Iron and Steel" in 1864;[1] it was stated that "iron and antimony unite readily by fusion, producing hard, brittle, white, easily fusible alloys of lower specific gravity than the mean of the specific gravities of the component metals." Cornelli[2] reported on a spark test on an iron-antimony alloy. Early work on iron-antimony alloys was also carried out by Laborde[3] and Maey.[4] Very few references were found on the physical and mechanical properties of antimony steel. French and Digges[10] tested certain high-speed steels, with a low tungsten and high vanadium content, containing up to 1·7% of antimony; they found that antimony adversely affected the hot-working properties and the tool life of the steel, while the hardness was not appreciably affected. Small amounts, of the order of 0·1–0·4% of antimony, did not affect the grain size of the steels after oil-quenching from 1290° C., but a higher antimony content tended to reduce it. The addition of antimony to commercial ferrous materials has been confined mostly to cast iron, and its influence on the properties of this material has been investigated fairly thoroughly; Guertler[7] found that the melting temperature was lowered and the metal became less viscous by the addition of antimony. Schwartz and

Guiler [8] stated that antimony tends to prevent the graphitisation of cast iron, this fact being confirmed later by Piwowarsky, Vladescu, and Nipper,[13] who considered that antimony is soluble in cementite. The latter authors found that in cast irons containing up to 1·2% of antimony the transverse and tensile strength, deflection and toughness were reduced, while the hardness and wear resistance were increased. In 1935 Piwowarsky [14] reported on the effect of antimony in pearlitic, martensitic and austenitic cast irons containing nickel. He found that antimony increased considerably the resistance of cast iron to alkali corrosion, while the addition of antimony to an alkali-resistant nickel-iron reduced the corrosion still

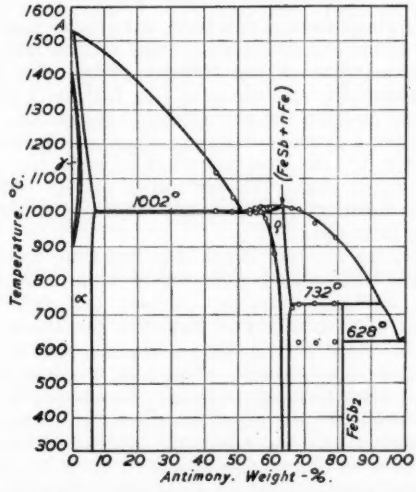

FIG. 1.—The Iron-Antimony Diagram (Vogel and Dannöhl [17])

further. Nickel was found to suppress the adverse effect of antimony on the mechanical properties.

The iron-antimony equilibrium diagram was evolved in 1908 by Kurnakow and Konstantinow,[5] and the general characteristics were confirmed later by Hägg.[12] The binary system was reinvestigated in 1934 by Vogel and Dannöhl,[17] who confirmed the results of Hägg by means of thermal and microscopical tests, with special reference to the homogeneous solid-solution alloys existing between 63·5 and 65·5% antimony. Wever [11] found that the iron-antimony alloys had a closed γ loop, the limit of solubility of antimony in γ-iron being given, by extrapolation, as 2%. Svetchnikoff and Gridnev,[21] however, gave the limit of the single γ-phase

field at 1150° C. as "about 2%," while at the same temperature the limit of the ($\gamma + \alpha$) field is reached at 4·5% antimony. W. D. Jones [15] estimated the limit of the γ loop at 4·25% antimony at 1150° C. The diagram given by Vogel and Dannöhl [17] is illustrated in Fig. 1. A wide solubility range of antimony in α-iron, found by Hägg [12] to be 6–7% at room temperature, is shown. Antimony, like arsenic, produces solid solutions of the interstitial type, the cube edge of α-iron saturated with antimony being 2·886 Å. [12] Portevin [6] carried out tests on the influence of antimony on the critical points of iron, but the results obtained did not throw light on the matter.

Production of Antimony Steels.

Most of the steels used in this work were made from liquid steel taken from a 1½-ton 3-phase Héroult basic electric furnace working a charge of steel turnings and foundry scrap. The authors are indebted to Messrs. Brown Lennox & Co., Ltd., of Pontypridd, for ready assistance given in the production of the steels. The charge was worked under a primary oxidising slag and a finishing reducing slag. After teeming, the steel was dead killed in the ladle by the addition of ¾ lb. of aluminium per ton of metal. Antimony was added as pure metal of 99·8% purity with a guaranteed arsenic content of not more than 0·02%.

Liquid steel for the test ingots was run from the ladle into a preheated shank lined with a composition made from a mixture of ground silica, firebrick, fireclay, ganister and coke breeze. A known amount of antimony was placed in the shank, which was filled to a 70-lb. mark with molten steel; the steel was then cast into preheated cast-iron moulds, 18 in. long and 3 in. in dia., each holding 30 lb. After teeming one ingot, the remaining steel in the shank was diluted with the original molten steel from the ladle to give approximately half the antimony content of the first ingot. Alloying was then continued, and by this means it was hoped that a fairly constant composition of the elements of the steel base would be obtained. All the ingots were of solid steel with a good surface and having a deep pipe. The chemical analyses of the steels are given in Table I.; the basic electric steels are *P*1 to *P*13. The loss of antimony was not so great as was expected, owing to the deoxidised nature of the molten metal and the rapid absorption of the element. The basic-electric steel was found to have about 0·3% each of silicon and copper, the latter being unexpectedly found on subsequent analysis. A McQuaid-Ehn test on steel *P*1 showed that it was a fine-grained steel, of grain size No. 7. Four steels containing higher antimony contents were made at a later date in a 20-lb. Ajax-Northrup high-frequency spark-gap furnace at University College, Cardiff, and the analyses of these (*HF*5 to *HF*23) are shown in Table I.; the carbon contents of these steels are, unfortunately, not equal. The charge of mild-steel scrap was

TABLE I.—*Chemical Analyses.*

Mark.	Carbon. %	Silicon. %	Manganese. %	Sulphur. %	Phosphorus. %	Copper. %	Antimony. %
*P*1	0·17	0·34	0·68	0·037	0·043	0·34	...
*P*2	0·18	0·32	0·68	0·034	0·044	0·32	0·14
*P*3	0·17	0·29	0·69	0·040	0·036	0·32	0·19
*P*4	0·17	0·30	0·68	0·041	0·031	0·33	0·24
*P*5	0·18	0·33	0·70	0·036	0·027	0·34	0·26
*P*6	0·17	0·31	0·64	0·041	0·035	0·33	0·30
*P*7	0·15	0·34	0·68	0·038	0·029	0·34	0·55
*P*8	0·18	0·30	0·62	0·037	0·030	0·34	0·59
*P*9	0·18	0·34	0·68	0·041	0·038	0·34	0·69
*P*10	0·16	0·31	0·66	0·033	0·040	0·33	1·45
*P*11	0·16	0·32	0·67	0·028	0·046	0·32	1·87
*P*12	0·16	0·32	0·67	0·028	0·043	0·33	2·02
*P*13	0·16	0·31	0·68	0·033	0·044	0·30	2·40
*HF*5	0·24	0·28	0·56	0·030	0·040	0·30	2·80
*HF*21	0·08	0·10	0·40	0·032	0·036	0·28	7·40
*HF*22	0·10	0·07	0·40	0·035	0·040	0·29	9·87
*HF*23	0·14	0·14	0·15	0·032	0·042	0·27	19·00

melted rapidly and the slag was thickened by small additions of silica and removed; the metal was then deoxidised completely by additions of ferro-silicon and ferro-manganese, the required amount of copper was added, and the addition of antimony was made prior to teeming. Only a small loss of antimony was experienced under these conditions.

Treatment of the Steel Ingots.

The works ingots were cropped with a circular saw to remove the pipe completely. No relation between the extent of piping and the antimony content was found. The standard treatment was to heat the ingots in a chain-smith's fire and to forge them under a compressed-air hammer to 1½ in. square. It was found that ingots containing up to 0·69% of antimony could be hot-forged without difficulty, but steels with higher antimony contents cracked at the corners even with light blows. No attempt was made to hot-forge the steels (shown in Table I.) containing 1·45% of antimony and over, as they would disintegrate under the hammer. Antimony therefore has a similar effect to that of arsenic on the hot-deformation of steel, as described by Houdremont and his collaborators.[20] The ingots *P*10 to *HF*23 were sectioned longitudinally, and were afterwards annealed. The forged bars were subsequently heated in a gas-fired furnace and hot-rolled, in a Robertson 3-high mill at the University, to a section 1 in. square for subsequent tensile bars, and to ⅝ in. square for subsequent impact test bars. The steels hot-rolled satisfactorily with up to 0·55% of antimony, but it was found necessary to heat the other two steels, containing 0·59% and 0·69% of antimony, to a higher temperature before rolling to prevent the formation of fine cracks at the corners.

Chemical Analysis of the Steels.

The determination of antimony in steel was found to be rather difficult until experience was obtained. Little help was obtained from text-books, and the method used after much experimenting entailed a separation of pure antimony sulphide from other constituents of the steel, and final titration with a standard solution of potassium bromate. The method was tested by the addition of known amounts of antimony, in the form of a standard solution, to the acid solution of the original steel; the following results were obtained:

Weight of Steel taken. G.	Antimony, %— Added.	Found.
10	Nil	0·012
10	0·050	0·060
5	0·60	0·61
2	1·50	1·49
1	4·0	4·03

It was found that the original steel actually contained a trace of antimony; the latter was not derived from the chemical reagents.

The determination of elements which necessitated the solution of the steel in nitric acid, such as phosphorus, also called for modifications in the usual method, owing to the formation of an insoluble residue of antimonic acid.

The Critical Ranges.

Heating and cooling curves of the steels were attempted by the inverse-rate and derived differential methods of thermal analysis, and while these tests gave good indications for certain critical points, a more definite indication of the Ac_3 temperature, which was particularly required, was provided by dilatometer tests. The temperature was measured by a platinum/platinum-rhodium thermocouple and a Cambridge potentiometer. The dilatometer curves are shown in Fig 2; they are of special interest, because they show the effect of antimony on the shape of the curve as well as on the temperatures of the critical range, which are also given in Table II. The rapid contraction of the steel above the Ac_1 temperature is prevented at an antimony content of 1·45%. The tests confirm that antimony raises the temperature of the Ac_3 transformation, which is progressively increased from 860° to 940° C., in steel containing 2·8% of antimony. The Ac_1 temperature is, however, practically constant in these steels. In the case of steel *HF*21, containing 7·4% of antimony, the curve shows that allotropic transformations are almost suppressed, and a contraction in length does not take place on heating. At 740° C., however, there is a slight, but definite, change in direction of the heating curve, showing a slower rate of expansion of the steel above this temperature, while at 945° C. the steel again resumes its normal rate. This suggested

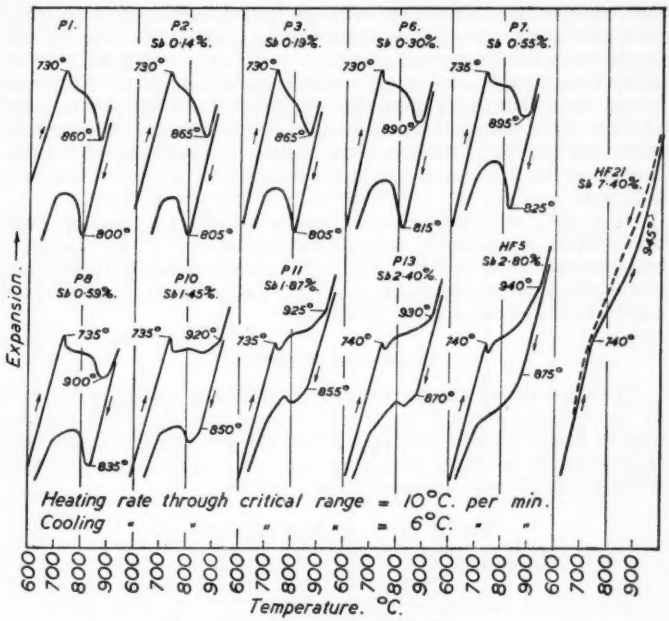

FIG. 2.—Heating and Cooling Curves.

TABLE II.—*Critical Ranges in Antimony Steels.*

Mark.	Antimony. %	Critical Range.			
		Heating Curve. ° C.		Cooling Curve. ° C.	
		Start.	Finish.	Start.	Finish.
*P*1	...	730	860	800	690
*P*2	0·14	730	865	805	690
*P*3	0·19	730	865	805	690
*P*4	0·24	730	865	805	690
*P*5	0·26	730	865	805	690
*P*6	0·30	730	890	815	695
*P*7	0·55	735	895	825	695
*P*8	0·59	735	900	830	695
*P*9	0·69	735	900	835	695
*P*10	1·45	735	920	850	700
*P*11	1·87	735	925	855	700
*P*12	2·02	735	927	860	700
*P*13	2·40	740	930	870	700
*HF*5	2·80	740	940	875	700

that the pearlite → austenite change had occurred, and that the austenite areas were being absorbed only with difficulty by the surrounding ferrite ground-mass. A quenching test from 760° C. showed the presence of small martensitic areas within the ferrite grains, thus confirming that the Ac_1 transformation had occurred and was not influenced by antimony. The low rate of absorption of the γ-iron areas, containing the carbon, by antimony-rich ferrite accounted for the almost negligible indications of critical points in the steel.

It is thus confirmed that antimony stabilises α-iron, although the pearlite → austenite transformation occurs at the constant temperature of 730–740° C. The high-antimony steels are practically non-hardenable by quenching, and have properties in line with other α-iron steels described by S. H. Rees.[16]

Mechanical Properties.

Heat treatment was carried out on the hot-rolled steels *P*1 to *P*9 by normalising them from a temperature 25° C. above the Ac_3 point. Steels *P*10 to *P*13 and *HF*5 were first annealed and then normalised from these temperatures. The high-antimony steels *HF*21 to *HF*23 were annealed from 1000° C.

TABLE III.—*Mechanical Properties.*

Mark.	Treatment.*	Antimony. %.	Limit of Proportionality. Tons per sq. in.	Yield Stress. Tons per sq. in.†	Max. Stress. Tons per sq. in.	Elongation on 2 in. %.	Reduction of Area. %.	Brinell Hardness Number.	Charpy Impact. Ft.lb. (Average).
*P*1	*R* and *N*	...	21·9	22·8	33·6	35·7	62·9	143	102
*P*2	*R* and *N*	0·14	22·8	23·2	33·7	35·9	62·8	147	102
*P*3	*R* and *N*	0·19	23·8	24·0	34·7	33·0	60·0	161	105
*P*4	*R* and *N*	0·24	23·8	24·3	34·9	33·4	60·0	162	70
*P*7	*R* and *N*	0·55	23·6	24·1	34·2	33·2	49·4	166	20
*P*8	*R* and *N*	0·59	24·0	25·0	34·6	30·5	45·5	170	12·5
*P*9	*R* and *N*	0·69	24·9	25·3	35·7	30·0	41·9	170	11·3
*P*10	*A* and *N*	1·45	26·3	27·2	27·4	2·5	1·7	170	8·4
*P*11	*A* and *N*	1·87	...	...	20·0	Nil	Nil	185	6·5
*P*12	*A* and *N*	2·02	...	...	19·6	Nil	Nil	185	6·8
*P*13	*A* and *N*	2·40	...	...	19·0	Nil	Nil	185	4·2
*HF*5	*A* and *N*	2·80	...	...	21·5	Nil	Nil	207	2·0
*HF*21	*A*	7·40	...	...	6·4	Nil	Nil	228	1·3
*HF*22	*A*	9·87	...	...	7·8	Nil	Nil	243	1·3
*HF*23	*A*	19·00	...	...	5·1	Nil	Nil	285	1·3

* *R* and *N* = rolled and normalised. *A* and *N* = annealed and normalised. *A* = annealed.
† Load giving 0·2% permanent set.

The results of the mechanical tests are shown in Table III. and in Fig. 3. The tensile strength is inappreciably affected by antimony, being raised by only 2 tons per sq. in. with an antimony content of 0·69%, while the ductility is decreased. At 1·45% of antimony the maximum stress becomes appreciably less than that of the original steel, and is practically equivalent to the limit of proportionality, while the ductility is reduced to negligible pro-

portions. Higher antimony contents still further reduce the tensile strength of the steels, which fracture without elongation, while steels with more than 7% of antimony have practically no tensile strength in the annealed condition. A marked embrittlement of the steels was found above 0·55% of antimony, as shown by an appreciable reduction in impact values, while the type of fracture of the impact test-piece changed to a coarse " crystalline " nature; steels

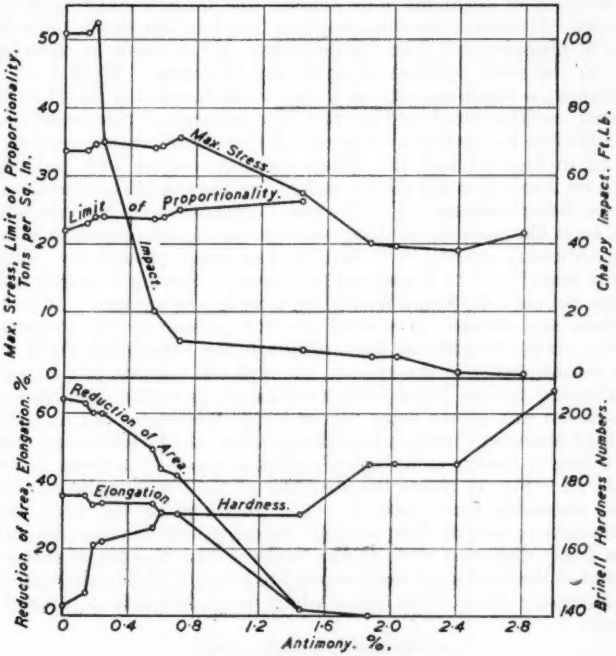

FIG. 3.—Mechanical Properties.

containing more than 1·45% of antimony showed still further embrittlement. Antimony thus has a similar influence on steel as arsenic [9] in reducing the impact values; the effect is also similar to that of phosphorus on 0·17% carbon steel,[20] but, for equal amounts, antimony acts more mildly on the tensile strength and impact properties. Antimony hardens steel progressively, although there is a fairly wide range of composition having the same hardness value. Although the high-antimony steels *HF*21 to *HF*23 were not very hard as revealed by the Brinell test, they were found to be

difficult to cut and machine, and caused excessive wear on high-speed tools. Steel containing 19% of antimony reacted like a mottled cast iron and was exceedingly difficult to machine.

The forged and rolled steels containing up to 0·69% of antimony all showed a fine grain size after normalising, examples of which are shown in Figs. 7 and 8. The annealed steels had a larger grain size, even after subsequent normalising, as shown in Fig. 9. Apart from the difference in grain size, the microstructures of the steels up to 2·8% of antimony were similar, and no new constituent was present. Excessive banding was not found in the steels, as in the case of phosphorus. The brittle nature of the steels is, therefore, due to the solid solution of antimony in ferrite. With 7·4% of antimony, a small amount of a new constituent was found in the casting, as illustrated in Fig. 21. The amount of this constituent increased as the antimony content of the steels became greater, as shown in Figs. 11 and 12. These structures agree with published work on iron-antimony alloys, which give the solubility of antimony in iron between 6 and 7%. The exact composition of the new phase has been the subject of disagreement among investigators of the iron-antimony system,[5, 12] but it has been proved by Hägg's X-ray tests [12] to be hexagonal in structure, having a homogeneity range between 63·5 and 65·5% of iron in the system. It is the ε phase and consists of a solid solution of iron in the compound FeSb. Hägg considered that, although the compound FeSb does not actually exist in the system, the unit cell consists of 2 iron and 2 antimony atoms, which form a lattice of the nickel arsenide type, the excess iron atoms being placed in the interstices of this lattice. In high-antimony steels containing pearlite, the latter is surrounded by a ring of ferrite, as in high-phosphorus steels,[16] as seen in Figs. 10 to 13. Fig. 13 shows the structure of the 9·87% antimony steel after annealing from 1000° C. The Fe–Sb phase has been taken into solution, and, on slow cooling, the compound has been deposited in a finely-dispersed state in the ferrite. The absence of the compound in the ferrite around the pearlite grains is due to the rejection of antimony from these areas which were formerly composed of γ-iron.

Carburising of the Steels.

The steels were carburised, in the form of specimens 2 cm. × 1 cm. × 1 cm. in dimensions, in a box packed with "Hardenite" case-hardening compound; they were heated for 6 hr. at 927° C., as in the McQuaid-Ehn grain-size test. The specimens were weighed and measured before and after the test, the increase in weight being taken as the amount of carbon absorbed by each steel. The carburised edges were examined under the microscope and the hardness of the surface was determined. A carburised specimen of each steel was also reheated to 780° C. in an electric furnace, under temperature control, and water-quenched to examine its response to case-hardening. The results are given in Table IV. and in Fig 4. There is a

TABLE IV.—*Carburising Test; 6 Hr. at 927° C.*

Mark.	Antimony. %.	Calc. Weight of Carbon Absorbed. Mg. per sq. cm.	Microstructure of Carburised Edge.*	Diamond Pyramid Hardness of Case.	
				As Carburised.	Quenched from 780° C.
*P*1	...	5·8	*P* (+ *C*)	240–260	980–1050
*P*2	0·14	4·2	*P* (+ *C*)	240–266	970–1040
*P*3	0·19	3·5	*P* (+ *C*)	245–270	970–1030
*P*4	0·24	4·0	*P* (+ *C*)	250–270	950–1020
*P*7	0·55	3·0	*P* + *F*	250–270	950–1000
*P*8	0·59	1·8	*P* + *F*	230–250	750– 870
*P*9	0·69	1·9	*P* + *F*	250–270	750– 870
*P*10	1·45	1·9	*P* + *F*	240–270	750– 850
*P*12	2·02	1·6	*P* + *F*	250–275	600– 700
*P*13	2·40	1·9	*P* + *F*	255–270	530– 615
*HF*5	2·80	0·8	*P* + *F*	270–275	550– 620
*HF*21	7·40	1·4	*P* + *F*	300–325	590– 600
*HF*22	9·87	2·0	*P* + *F*	350–380	570– 590
*HF*23	19·00	...	*P* + *F*	300–310	450– 500

* *P* = Pearlite. *C* = Cementite. *F* = Ferrite.

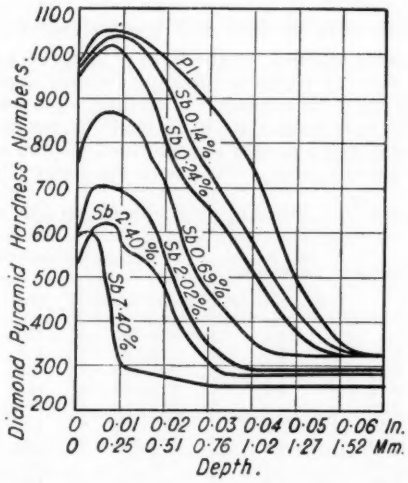

FIG. 4.—Depth of Hardness of Carburised Steels Water-Quenched from 780° C.

definite decrease in the amount of carbon which has diffused into the steels with increasing antimony contents. This would be expected in view of the fact that the metal stabilises α-iron, and

therefore would retard the diffusion of carbon. Sodium-picrate etching showed that a hyper-eutectoid zone was formed only in steels containing up to 0·24% of antimony; with 0·55% of antimony, an abnormal case was produced showing a ferrite + pearlite structure, although a narrow marginal layer consisted chiefly of pearlite. Above 0·55% of antimony, ferrite areas extended to the edge. The greater hardness of the carburised steels with increasing antimony is due to the hardening produced by their antimony content. It was observed that the grain size of the core metal after carburising was much finer in steels containing 0·59–0·69% of antimony than in other steels. On quenching, practically the same hardness value was obtained in the surface layers of steels containing up to 0·55% of antimony, although the depth of case is somewhat decreased. Above 0·55% of antimony, however, both the hardness of the quenched steel and the depth of case were progressively lowered.

The normal response to carburising shown by 0·24% antimony steel is illustrated in Figs. 14 and 15, while various ferritic structures in other steels are depicted in Figs. 16 to 23. Figs. 21 to 23 are interesting, as they show the type of structures obtained with increased carbon on steels with high antimony contents; spheroidising of the Fe–Sb compound has occurred.

Response of the Steels to Nitrogen-Hardening.

The steels were nitrided, in the form of 2 cm. × 1 cm. × 1 cm. specimens, in the experimental nitriding furnace described in the publications of one of the authors.[24] Ammonia gas was passed over the steels, which were heated to 550° C. for 48 hr. under temperature control. A fairly rapid rate of gas was used to give a dissociation of 20–30% in the exit gases. The results are given in Table V.

TABLE V.—*Nitriding Test; 48 Hr. at 550° C.*

Mark.	Antimony. %	Calc. Weight of Nitrogen Absorbed. Mg. per sq. cm.	Diamond Pyramid Hardness.		
			Nitrided Layer.	Core.	Increment.
*P*1	...	10·2	220–280	150	130
*P*2	0·14	9·5	230–290	154	136
*P*3	0·19	7·0	240–300	166	134
*P*4	0·24	6·3	250–300	169	131
*P*7	0·55	4·8	268–305	174	131
*P*8	0·59	3·2	270–300	177	123
*P*9	0·69	3·0	280–305	180	125
*P*10	1·45	2·8	300–320	186	134
*P*11	1·87	1·8	305–355	195	160
*P*12	2·02	1·8	330–355	196	159
*P*13	2·40	1·8	340–360	200	160
*HF*5	2·80	1·7	430–490	215	275
*HF*21	7·40	2·0	310–340	230	110
*HF*22	9·87	2·4	340–360	250	110
*HF*23	19·00	1·0	325–350	290	60

The specimens were weighed and measured before and after treatment, as in the carburising test; the increase in weight was taken to represent the amount of nitrogen absorbed. As in carburising, the steels absorbed less of the diffusing element with increasing antimony contents. The hardening produced was insignificant, the maximum diamond hardness found being 490 in the 2·8% antimony steel; with higher antimony, a lower hardness increment was obtained. The microstructures illustrated in Figs. 24 to 27 show that, while the outer layer of the ε phase of iron nitride becomes less with increasing antimony in the steel, the γ' phase of Fe_4N, in the form of nitride "needles," is present in all steels. Antimony is thus of no value in nitriding, because of the poor mechanical properties of the steel and as it is incapable of forming fine insoluble particles of alloy nitride necessary to induce dispersion-hardening.

Quench-Ageing Tests.

Quench-ageing tests were carried out to find if antimony had any effect on quench-age-hardening. The steels, of approximately similar dimensions, were quenched together in water from 680° C. They were tested for hardness within 30 min. and again tested at intervals until the maximum hardness occurred. The results are given in Table VI. All steels age-hardened to a greater degree than

TABLE VI.—*Quench-Ageing. Quenched from* 680° *C. and Aged.*

Mark.	Antimony. %	Hardness after Ageing for 30 Min.	Hardness Increment.	
			After Ageing for 1 Week.	At Time of Max. Ageing.
*P*1	...	177	5	14
*P*2	0·14	178	10	24
*P*3	0·19	179	17	29
*P*4	0·24	180	19	32
*P*7	0·55	180	23	45
*P*8	0·59	182	15	31
*P*9	0·69	194	10	26
*P*10	1·45	202	9	20
*P*11	1·87	209	11	22
*P*12	2·02	215	9	17
*P*13	2·40	215	8	15

the original steel *P*1. The hardness was progressively increased, on ageing, in steels containing up to 0·55% of antimony, above which amount a gradual decrease again occurred. It is probable that antimony influences the amount of carbon retained in solid solution in ferrite. This amount may be inappreciably affected in steels with 0·55% and less of the element, although, on ageing, the degree of hardening is greater with increasing antimony, owing to the greater ease by which the carbide is rendered insoluble,

thus causing greater distortion. With a higher antimony content there is possibly less carbon retained in solid solution, with a consequent decrease in the degree of age-hardening.

Cementation with Antimony.

The cementation of iron and copper by antimony dust has been investigated by Kase [18] at temperatures between 350° and 1000° C. The rate of diffusion increased with rise in temperature and the cemented surface was stated to offer good corrosion-resistance to 10% sulphuric acid. The diffusion of antimony into Sb–Fe alloys was examined by W. D. Jones [15] in order to find the extent of the γ loop, the limit of which he fixed as $4\frac{1}{4}$% of antimony at 1150° C.

Preliminary tests on cementation were carried out by packing samples of Armco iron and mild steel in a steel box with a mixture of 49% of antimony powder + 49% of alumina + 2% of ammonium chloride, which is a familiar composition used with aluminium powder for calorising. The cover was luted down with a mixture of Stourbridge clay and asbestos, and the box was later heated to and retained at 900° C. for 6 hr. It was found that an excessive amount of Fe–Sb alloy had cemented on the metal surfaces in irregular growths. Better results were obtained by decreasing the amount of antimony powder (90 mesh), and omitting the ammonium chloride. A more even coating of alloy was obtained by using an intimate mixture of 20% of antimony + 80% of alumina, the steels being heated at 900° C. for 3 hr. It was found that approximately 3 g. of antimony had diffused into the steel, having a surface area of 10 sq. cm., to form a firm Fe–Sb alloy. Specimens of steel *P*1 were cemented in this manner, in the form of 1-in. dia. specimens, $\frac{1}{8}$ in. thick, and drilled with an $\frac{1}{8}$-in. hole, for use in subsequent corrosion tests. Microstructures of the cemented edges are shown in Figs. 28 to 30. Fig. 28 is Armco iron, in which several layers are formed. Next to the iron is a solid solution of antimony in iron, adjacent to which is the ε phase of Fe–Sb; this is followed by a layer containing crystals of the latter set in the compound $FeSb_2$. Figs. 29 and 30 represent mild steels of different grain size, which show a columnar diffusion zone of carbon-free ferrite solid solution of antimony (denoting a phase change), together with an outer zone containing the ε phase of the Fe–Sb compound. No columnar ferrite crystals are formed in Armco iron, as the temperature of cementation was below the Ac_3 point (927° C.), which is in accordance with the findings of W. D. Jones.[15]

Atmospheric Corrosion Tests.

Small discs were sectioned from the heat-treated bars, approximately 1 in. in dia. and $\frac{1}{8}$ in. in thickness, and a hole $\frac{1}{8}$ in. dia. was drilled in each near the periphery. They were ground and polished

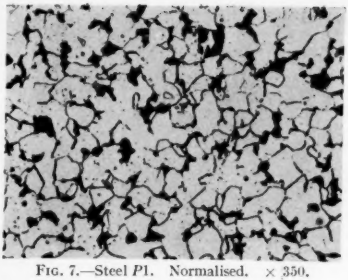

FIG. 7.—Steel *P*1. Normalised. × 350.

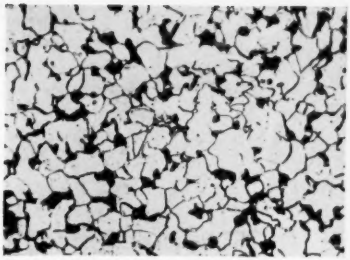

FIG. 8.—Antimony 0·59%. Normalised. × 350.

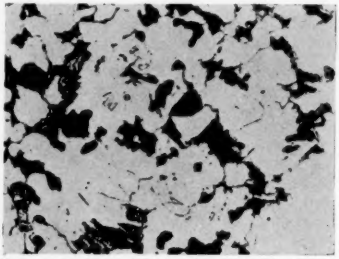

FIG. 9.—Antimony 2·80%. Annealed and normalised. × 350.

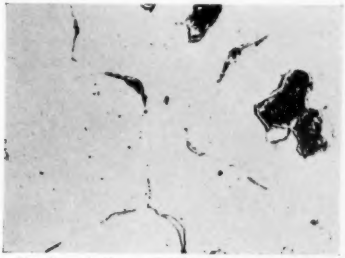

FIG. 10.—Antimony 7·40%. As cast. × 350.

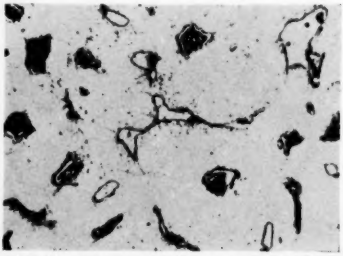

FIG. 11.—Antimony 9·87%. As cast. × 350.

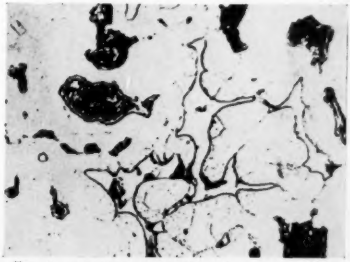

FIG. 12.—Antimony 19·00%. As cast. × 350.

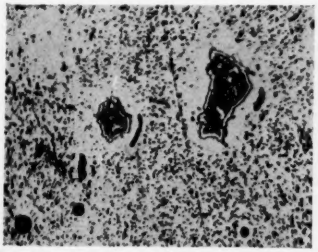

FIG. 13.—Antimony 9·87%. Annealed at 1000° C. × 350.

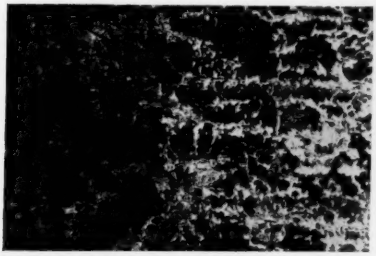

FIG. 14.—Antimony 0·24%. Carburised. × 50.

(Micrographs reduced to three-quarters linear in reproduction.)

[*Jones and Morgan.*
[*To face p.* 128 P.

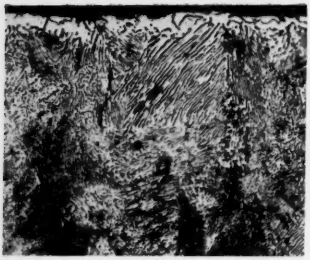

FIG. 15.—Antimony 0·24%. Carburised. × 350.

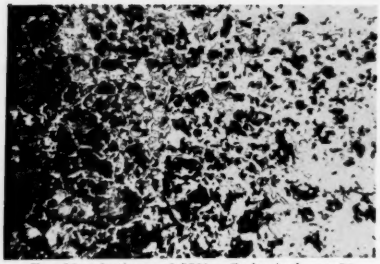

FIG. 16.—Antimony 0·55%. Carburised. × 50.

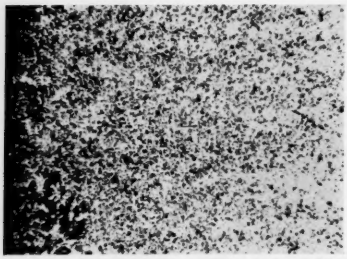

FIG. 17.—Antimony 0·69%. Carburised. × 50.

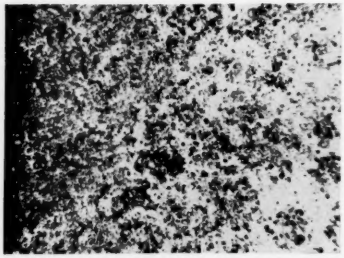

FIG. 18.—Antimony 1·45%. Carburised. × 50.

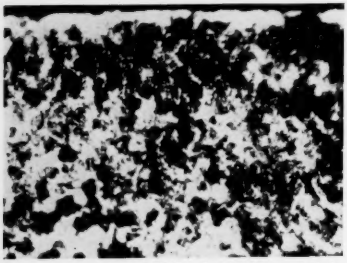

FIG. 19.—Antimony 0·59%. Carburised. × 350.

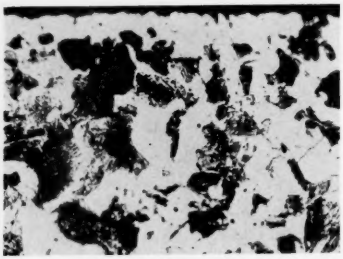

FIG. 20.—Antimony 2·40%. Carburised. × 350.

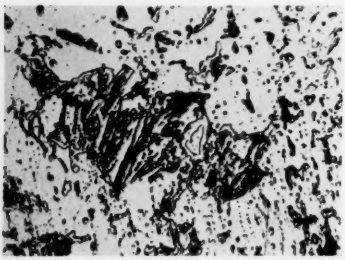

FIG. 21.—Antimony 7·40%. Structure in carburised edge. × 350.

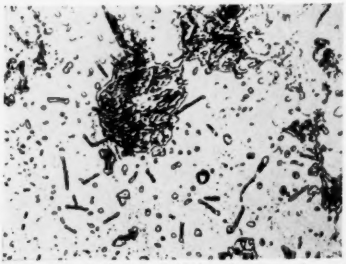

FIG. 22.—Antimony 9·87%. Structure in carburised case. × 350.

(Micrographs reduced to three-quarters linear in reproduction.)

[Jones and Morgan.

FIG. 23.—Antimony 19·00%. Structure in carburised edge. × 350.

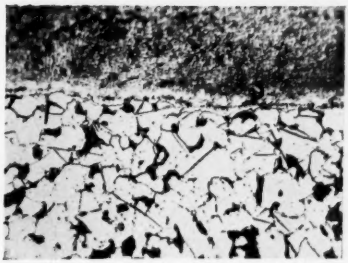

FIG. 24.—Steel *P*1. Nitrided. × 350.

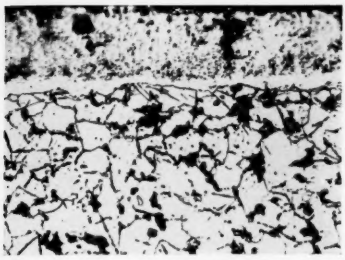

FIG. 25.—Antimony 0·69%. Nitrided. × 350.

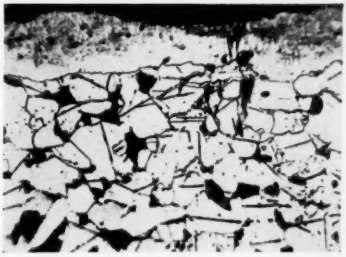

FIG. 26.—Antimony 1·45%. Nitrided. × 350.

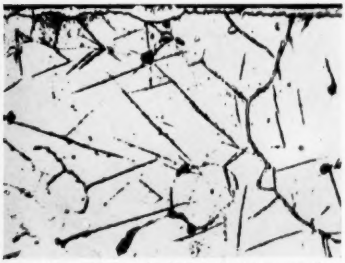

FIG. 27.—Antimony 19·00%. Nitrided. × 350.

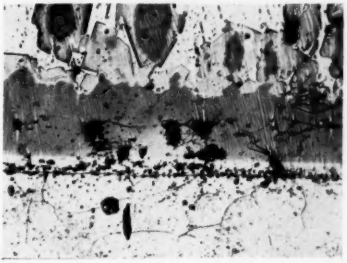

FIG. 28.—Armco Iron Cemented with Antimony at 900° C. × 100.

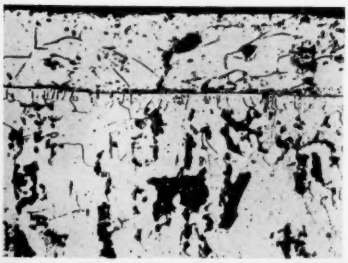

FIG. 29.—0·15% Carbon Steel Cemented with Antimony at 900° C. × 100.

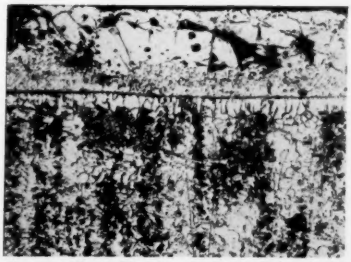

FIG. 30.—Steel *P*1 Cemented with Antimony at 900° C. × 100.

(Micrographs reduced to three-quarters linear in reproduction.)

[*Jones and Morgan.*

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down to 00 emery, cleaned with benzene, weighed, and measured. Exposure of the steels was carried out in the chemical laboratory. The specimens were supported on glass hooks in a tank which contained about 1 in. of water at the bottom to provide a humid atmosphere. The specimens were sprayed with tap water twice a day, to give alternate wetting and drying of the surfaces. In view of the greater resistance of some of the steels to dilute sulphuric acid, &c., water was used rather than dilute acid or salt solutions, the chief object being a comparison of the corrosion resistance of the steels under standard conditions. A specimen of steel *P*1, cemented with antimony, was also included. The steels were weighed at intervals up to 40 days, after previously drying them in desiccators, and the increase in weight was observed. The treatment was then continued for a period up to 100 days after which time the products of corrosion were removed electrolytically. This was done by making each specimen the cathode in a 10% sodium cyanide electrolyte, using a platinum foil anode, at a current density of 15 amp. per sq. ft. (as described in the First Report of the Corrosion Committee[22]). The results are given in Table VII.; they represent corrosion on a

TABLE VII.—*Atmospheric Corrosion.*

Mark.	Antimony. %	Gain in Weight after 40 Days' Exposure. Mg.	Loss in Weight after 100 Days' Exposure (derusted electrolytically). Mg.
*P*1	...	62	118
*P*2	0·14	63	150
*P*3	0·19	62	120
*P*4	0·24	57	115
*P*7	0·55	56	108
*P*8	0·59	57	110
*P*9	0·69	54	107
*P*10	1·45	55	109
*P*11	1·87	55	105
*P*12	2·02	46	94
*P*13	2·40	48	88
*HF*5	2·80	49	86
*HF*21	7·40	22	48
*HF*22	9·87	35	58
C *	...	4	5

* Steel *P*1 cemented with antimony.

surface area of 2 sq. in., the weights being adjusted for any slight differences in area. All the specimens soon developed a coating of rust, and while the steels with less than 0·2% of antimony corroded to a greater extent than the mild steel, the other steels all showed an increased resistance to corrosion. This was particularly evident in steels above 2% of antimony. The cemented steel was extremely resistant.

Scaling Test.

A preliminary test at 1000° C. proved, as anticipated, that antimony imparted practically no anti-scaling qualities, a slight improvement shown having no practical interest. It was observed in high-antimony steels, and especially in the cemented steel, that an enrichment of antimony had occurred at the scale/metal interface as compared with the outer layer, as found by Kiwit [23] on the effect of alloying elements on the scaling of steel.

Resistance to Acids.

These tests were carried out on small test pieces 1 in. in dia., $\frac{1}{8}$ in. thick, having a small hole drilled in each for support, as described in the atmospheric corrosion tests. They were tested for resistance to sulphuric and hydrochloric acids of 5% and 25% strength by volume, and to 5% nitric acid; Analar grade of acids was used. Each specimen was suspended, from a glass hook support, in the centre of 250 ml. of the acid solution contained in a 400-ml. beaker. The temperature of the acids was adjusted prior to the test to 25° C., and the beakers were then placed in a water-bath, the temperature of which was also adjusted to 25° C. The temperature of the bath was thermostatically controlled, and the tests were carried out for periods of 1, 4 and 24 hr. The procedure was to withdraw each specimen after 1 hr. immersion, wash it in water, wipe away any surface residue of carbides, &c., wash it in rectified spirits and dry. It was weighed and again immersed in the same acid solution for a further 3 hr., after which the same procedure was carried out; it was then immersed for a further 20 hr. A test in 5% nitric acid showed that considerable attack had taken place after 4 hr., so that a longer period was not necessary. The results of the tests are given in Tables VIII. to XII.

Tests in 5% and 25% Sulphuric Acid.

It was observed, during the chemical analysis of drillings, that high-antimony steels dissolved in dilute sulphuric acid more slowly than the original steel *P*1, much of the antimony being found in the insoluble residue. These tests in sulphuric acid showed that steels with a low antimony content corroded to a greater extent than the original steel. Thus in 5% sulphuric acid, steel containing 0·14% of antimony, and in 25% sulphuric acid, steels containing 0·14–0·24% of antimony, were corroded more than steel without antimony. With higher antimony contents, however, the acid attack became gradually less, the lowest value being found at approximately 10% of antimony, as shown in Tables VIII. and IX. Some of the results are illustrated in Fig. 5. The antimony-cemented steel was specially resistant to attack. Similar tests carried out

TABLE VIII.—5% *Sulphuric Acid at* 25° *C.*

Mark.	Antimony. %.	Loss in Weight. Mg. per sq. cm.		
		1 Hr.	4 Hr.	24 Hr.
*P*1	...	1·0	3·0	18·5
*P*2	0·14	1·3	3·5	20·2
*P*3	0·19	1·0	2·5	11·6
*P*4	0·24	1·1	3·2	13·4
*P*7	0·55	1·2	3·0	9·7
*P*8	0·59	1·2	2·7	7·2
*P*9	0·69	1·2	2·4	6·5
*P*10	1·45	1·2	2·0	5·8
*P*11	1·87	1·0	1·7	6·0
*P*12	2·02	0·8	1·2	5·8
*P*13	2·40	0·6	0·9	5·8
*HF*5	2·80	0·4	0·8	5·2
*HF*21	7·40	0·1	0·5	3·2
*HF*22	9·87	0·0	0·1	2·5
C *	...	0·0	0·0	0·6

* Steel *P*1 cemented with antimony.

TABLE IX.—25% *Sulphuric Acid at* 25° *C.*

Mark.	Antimony. %.	Loss in Weight. Mg. per sq. cm.		
		1 Hr.	4 Hr.	24 Hr.
*P*1	...	1·8	4·6	38·0
*P*2	0·14	2·5	6·6	44·9
*P*3	0·19	2·1	4·8	42·0
*P*4	0·24	2·1	6·0	44·7
*P*7	0·55	1·8	5·3	30·0
*P*8	0·59	1·4	3·2	22·8
*P*9	0·69	1·2	2·5	21·0
*P*10	1·45	1·1	2·8	20·0
*P*11	1·87	1·2	2·5	19·2
*P*12	2·02	1·1	1·8	9·8
*P*13	2·40	0·9	1·6	8·0
*HF*5	2·80	0·8	1·5	7·2
*HF*21	7·40	0·6	0·9	6·0
*HF*22	9·87	0·0	0·2	4·8
C *	...	0·0	0·0	0·8

* Steel *P*1 cemented with antimony.

on another mild steel, of low copper content and of larger grain size, showed a greater attack than on the steel *P*1. Irregular results were obtained on the 19% antimony steel and are not reported.

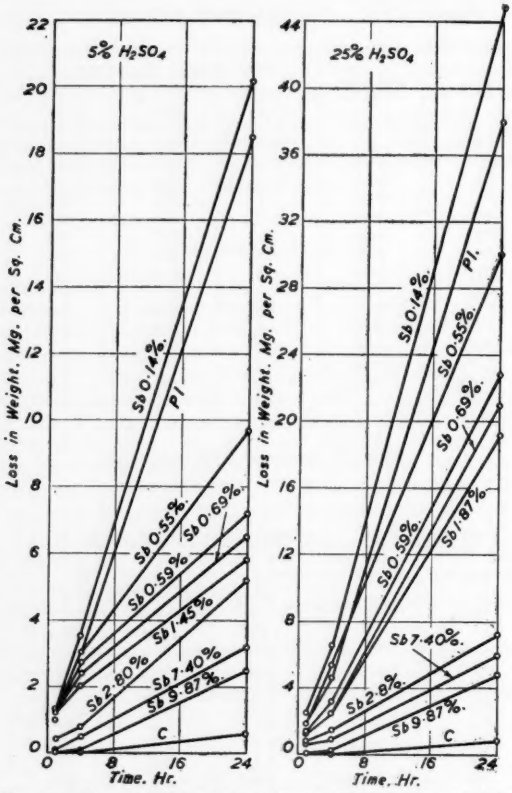

FIG. 5.—Corrosive Attack by 5% and 25% Sulphuric Acid.

Tests in 5% and 25% Hydrochloric Acid.

While less attack of the steels was generally found in 5% hydrochloric acid than in 5% sulphuric acid, the 0·14% antimony steel was again corroded to a greater extent than the original steel. The attack became less, however, with higher antimony contents. In 25% hydrochloric acid, also, the 0·14% antimony steel was attacked to a greater extent than steel *P*1. Steels containing up to 0·55% of antimony were corroded to approximately the same extent, while with higher antimony, the resistance of the steels, although slightly less, was practically constant. Although steels containing less than 2% of antimony were attacked to a less extent by 25% hydrochloric

acid than by 25% sulphuric acid, steels with higher antimony contents resisted attack by the latter to a greater degree. The antimony-cemented steel was found to be only inappreciably attacked by both acids. Results are shown in Tables X. and XI. and in Fig. 6.

TABLE X.—5% *Hydrochloric Acid at* 25° *C.*

Mark.	Antimony. %	Loss in Weight. Mg. per sq. cm.		
		1 Hr.	4 Hr.	24 Hr.
*P*1	...	0·5	1·3	10·8
*P*2	0·14	1·0	2·0	12·0
*P*3	0·19	0·6	1·4	9·4
*P*4	0·24	0·6	1·5	8·0
*P*7	0·55	6·7	1·6	6·9
*P*8	0·59	0·6	1·5	5·5
*P*9	0·69	0·7	1·5	6·0
*P*10	1·45	0·8	1·4	6·0
*P*11	1·87	0·6	1·3	4·5
*P*12	2·02	0·6	1·1	4·0
*P*13	2·40	0·3	0·9	4·0
*HF*5	2·80	0·2	0·7	4·0
*HF*21	7·40	0·2	0·7	4·4
*HF*22	9·87	0·0	0·0	1·6
C *	...	0·0	0·0	0·7

* Steel *P*1 cemented with antimony.

TABLE XI.—25% *Hydrochloric Acid at* 25° *C.*

Mark.	Antimony. %	Loss in Weight. Mg. per sq. cm.		
		1 Hr.	4 Hr.	24 Hr.
*P*1	...	1·6	4·5	28·4
*P*2	0·14	1·8	4·7	29·4
*P*3	0·19	1·3	4·4	23·6
*P*4	0·24	1·4	4·4	25·2
*P*7	0·55	1·4	4·2	24·4
*P*8	0·59	1·3	3·3	15·5
*P*9	0·69	1·2	3·1	12·8
*P*10	1·45	1·3	3·0	14·7
*P*11	1·87	1·3	2·6	13·6
*P*12	2·02	1·3	2·5	12·6
*P*13	2·40	1·3	2·3	13·5
*HF*5	2·80	1·1	2·2	13·0
*HF*21	7·40	0·5	1·6	12·5
*HF*22	9·87	0·6	1·4	12·0
C *	...	0·0	0·2	1·0

* Steel *P*1 cemented with antimony.

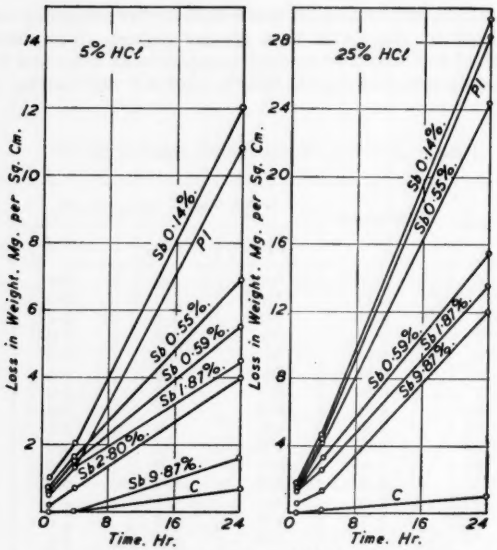

FIG. 6.—Corrosive Attack by 5% and 25% Hydrochloric Acid.

Tests in 5% Nitric Acid.

All the steels corroded appreciably in this acid, and although the steels with high antimony contents were attacked to a less extent, they are practically non-resistant to the acid. During etching of the steels, however, in 4% alcoholic nitric acid for microscopical examination, it was found that a longer time was necessary to etch the high-antimony steels as compared with the low-antimony steels. The antimony-cemented steel was again found to be highly resistant to attack, although to a less extent than in other acids. It also resisted 25% nitric acid to an appreciable degree.

Summary and Conclusions.

(1) A series of killed steels, containing up to 19% of antimony, have been made and some of the useful properties have been determined. Like arsenic and phosphorus, other elements in group VB. of the Periodic Table, it embrittles steel when present in sufficient quantity, being dissolved in α-iron and stabilising it.

(2) Steels with 0·17% of carbon and up to 0·69% of antimony can be hot-forged and rolled. Higher rolling temperatures are necessary above 0·55% of antimony. Red-shortness occurs in

steels containing more than 0·69% of antimony, and a 1·45% antimony steel cannot be hot-worked without disintegration. Antimony has an inappreciable strengthening effect on the tensile properties of steel, 0·69% raising the maximum stress value by only 2 tons per sq. in., while the ductility and impact values are decreased. Higher antimony steels have little tensile strength and are seriously embrittled.

(3) The A_1 point is practically unaffected by antimony, but the A_3 temperature is progressively raised. With 2·8% of antimony

TABLE XII.—5% *Nitric Acid at* 25° *C.*

Mark.	Antimony. %	Loss in Weight. Mg. per sq. cm.	
		1 Hr.	4 Hr.
*P*1	...	90	233
*P*2	0·14	91	227
*P*3	0·19	79	190
*P*4	0·24	78	168
*P*7	0·55	91	205
*P*8	0·59	90	188
*P*9	0·69	80	160
*P*10	1·45	78	155
*P*11	1·87	86	182
*P*12	2·02	75	140
*P*13	2·40	73	165
*HF*5	2·80	72	170
*HF*21	7·40	56	152
*HF*22	9·87	44·4	124
C *	...	1·1	4·7

* Steel *P*1 cemented with antimony.

the Ac_3 is raised from 860 to 940° C. High-antimony steels are practically non-hardenable, owing to a stabilised ferrite structure.

(4) Antimony contents up to 0·24% do not adversely effect carburising or case-hardening properties, but larger amounts cause abnormal structures, and a consequent soft case on quenching.

(5) The response of the steels to nitrogen-hardening is negligible.

(6) Cementation of steel with antimony powder is readily effected and the cemented steel is highly resistant to atmospheric corrosion and to acid attack.

(7) Steels with a low antimony content are more susceptible to atmospheric and acid corrosion than carbon steel. With increasing antimony, however, the steels become more resistant.

(8) Above 0·55% of antimony the steels are increasingly resistant to attack by 5% and 25% sulphuric acid at 25° C. They resist attack by hydrochloric acid to a less degree.

Acknowledgments.

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DECARBURISATION OF GRANULATED PIG IRON: THE "R.K." PROCESS.[1]

By Professor Count BO KALLING and IVAR RENNERFELT, Civilingeniör, Fil. Kand. (Stockholm).

(Figs. 9 to 13 = Plates XXI. and XXII.)

Summary.

The authors have invented a new method, the "R.K." process, for converting pig iron into a product with a low carbon content, which is suitable as a substitute for steel scrap for remelting in steel furnaces. The iron tapped from the blast-furnace is granulated in the molten condition in an appliance which is illustrated. The granulated iron is fed continuously into a rotary furnace, where it is decarburised without melting in a gas mixture containing carbon dioxide and carbon monoxide in such proportions that decarburisation takes place practically without the simultaneous oxidation of iron or other metallic constituents. Decarburisation down to very low carbon contents is possible. The composition of the gas mixture in the furnace is regulated by burning the reaction gas leaving the charge together with some blast-furnace gas with air, which is blown in a special way towards the inclined surface of the revolving charge. The consumption of blast-furnace gas is very low on account of the exothermal character of the process, and in continuous operation practically no addition of fuel will be necessary if the residual carbon content of the product is not to be especially low. In principle, the "R.K." process thus has a close resemblance to the Bessemer process.

In the paper the theory of the process is discussed, and the results are given of experiments in the laboratory and on a small technical scale, and from the first furnace operating on a full industrial scale.

At the beginning of 1936 the project was brought up of producing a low-carbon raw material, suitable for certain steel-making processes, by decarburising pig iron in granulated form. The matter was taken up by the Technical Research Department of Jernkontoret, and some preliminary laboratory experiments were started in order to investigate the possibility of utilising this refining method. As the results were favourable, the Research Department made a grant for experiments to be carried out on a technical scale. The first trials on a bigger scale were made at the Avesta Steelworks in a small already-existing rotary furnace. Here the process assumed in principle its present form. The first plant for industrial production was erected at the Fagersta Steelworks and was put in operation at

[1] Received July 29, 1939.

the beginning of 1938, after preliminary experimental work had been done in order to find an appropriate method of granulation.

The possibility of decarburising pig iron without melting has long been known and utilised for making malleable cast iron. The principle of decarburisation without melting has, however, also been applied to steel production, though to a limited extent. An example thereof is the dry carbon refining method worked out by P. Tunner, of Leoben, in the middle of the nineteenth century. In this method the pig iron was cast in flat bars, about 15 mm. thick, which were then annealed in boxes embedded in pulverised iron ore. The heating time amounted to 2½–3 months. The method was not in use for long, because of the invention of the Bessemer process.

Another method of decarburisation without melting is the Uchatius process. The basis material here is granulated pig iron, which, in admixture with iron ore, is successively heated in crucibles to melting. The main part of the decarburisation in this process takes place before the melting starts. This method, which is said to have been in use in England already at the end of the eighteenth century, was taken up and exploited by Uchatius in a somewhat modified form about 1850. The method was then introduced at the Wikmanshytte Steelworks in Sweden, and has been in use there ever since.

The so-called "R.K." process now developed differs from previous methods chiefly in the fact that carbon is oxidised by means of gaseous oxygen instead of iron oxides, and that the process is carried on continuously by feeding the material through a rotary furnace while being simultaneously mixed. In the following, a short description is given of the experimental work and of results obtained in plants in actual operation.

Theory and Laboratory Experiments.

Equilibrium of the Decarburisation Reaction.

The method previously applied, of using iron ore as an oxidising agent, has considerable drawbacks. During the process the ore develops a strong tendency to sinter as soon as the temperature approximates to 1000° C. As a process of this kind must be continuous, and as the charge must consequently be kept moving without balling together or sticking to the furnace walls, the working temperature has to be limited to not more than about 1000° C., if much iron ore is used in the charge. Another inconvenience is that the reaction between the ore and the carbon is endothermic, for which reason a not inconsiderable amount of heat must be added beyond that required for the heating of the charge.

The experiments were therefore directed towards using a gas mixture containing carbon monoxide and dioxide as an oxidising agent, these gases being applied in such proportions that the carbon was oxidised but not the iron. Owing to the absence of ore the

charge of granulated iron can be heated to a considerably higher temperature without any tendency to sintering, which makes the reaction more rapid and complete. If the heat content of the reaction gas can be utilised for carrying out the process, this becomes exothermic and is thus facilitated.

Fig. 1 shows how far the carbon content can be lowered on decarburising iron in a gaseous atmosphere containing carbon monoxide and dioxide at a combined pressure of 1 atm. The diagram, which has been worked out by G. Phragmén from thermodynamic calculations,[1] agrees in its main features with the experimental results

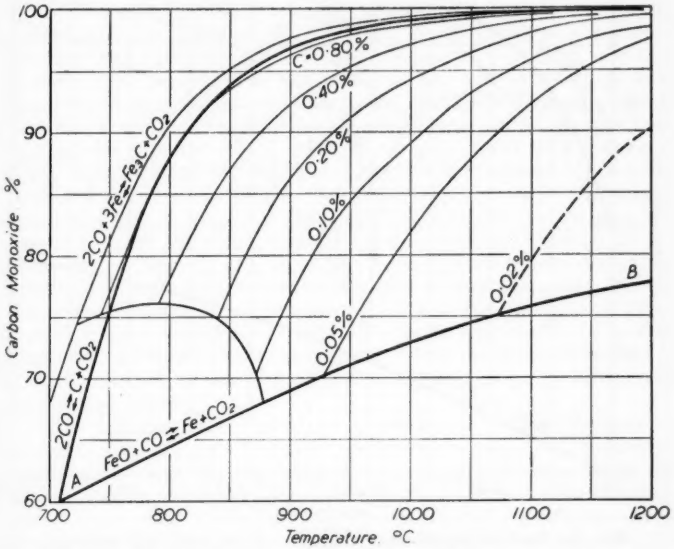


FIG. 1.—Fe–C–O Equilibrium Diagram. $(CO) + (CO_2) = 1$ atm.

previously presented by A. Johansson and R. von Seth.[2] The form and relative positions of the curves will, however, be more reliable in the *calculated* diagram and, besides, the displacement of the lines due to change of pressure can be more easily obtained from it.

In order to decarburise without simultaneous oxidation of the iron, the carbon monoxide content of the gas phase must, according

[1] B. Kalling, *Jernkontorets Annaler*, 1934, vol. 118, p. 87.
[2] A. Johansson and R. von Seth, *Journal of the Iron and Steel Institute*, 1926, No. II., p. 295.

to the diagram, lie above the line AB, which represents the equilibrium for the reaction $FeO + CO = Fe + CO_2$. As this reaction takes place without change of volume, the position of equilibrium is independent of the total pressure, *i.e.*, the ratio $CO : CO_2$ is not altered, even if the gas is diluted with other gases.

The " isocarbons " entered in the diagram indicate the influence of the temperature on the composition of the gas in equilibrium with a certain carbon content. They correspond to the equilibrium of the reaction $2\,CO \rightleftharpoons C + CO_2$. As this reaction takes place with a

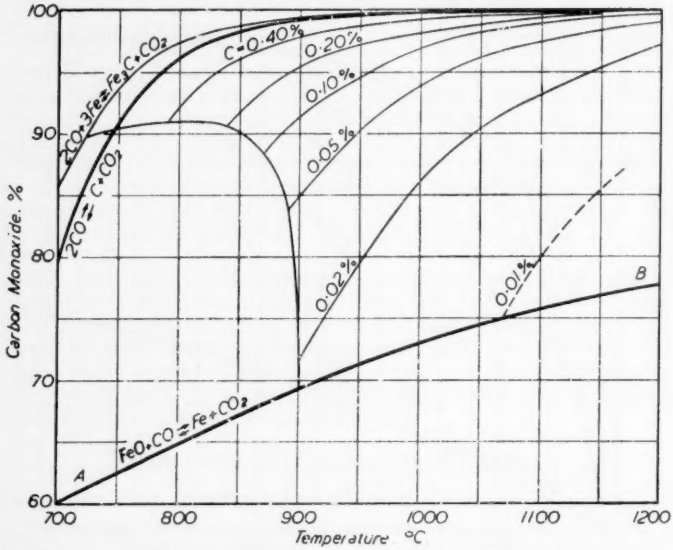


FIG. 2.—Fe–C–O Equilibrium Diagram. $(CO) + (CO_2) = 0{\cdot}25$ atm.

change of volume, the ratio $CO : CO_2$ is influenced by the combined pressure of these gases in such a way that, for a constant $CO : CO_2$ ratio, a decrease in pressure causes a decrease in carbon content. The diagram in Fig. 2 shows how the isocarbons are displaced if the combined pressure of the carbon monoxide and the carbon dioxide is lowered to 0·25 atm., for instance, by dilution with nitrogen.

The decarburisation is generally favoured by an increase in temperature. At 1000° C. it should thus be possible, without oxidation of iron, to lower the carbon to about 0·04% if the combined pressure of carbon monoxide and dioxide is 1 atm. (Fig. 1), and at

1100° C. to about 0·02%. If the pressure is reduced to only 0·25 atm. (Fig. 2), equilibrium even at 1000° C. lies at about 0·01%.

The results of a number of tests made in the laboratory have in the main been in very good agreement with the diagrams.

It is thus possible at such a moderate temperature as 1000° C. to lower the carbon to values that are difficult to obtain by fusion refining processes. However, in order that a process may be utilised technically a sufficiently high rate of decarburisation is also necessary.

Rate of Decarburisation.

There are nowadays certain possibilities of calculating the rate of decarburisation theoretically. It is to be supposed that the decarburisation takes place mainly by the diffusion of the carbon through the austenite phase to the surface of the grain, where it is successively removed by the reaction $CO_2 + C \rightarrow 2CO$. According to one opinion, not seldom heard, the decarburisation should also be caused by the diffusion of oxygen and carbon dioxide from the outside into the metal, where these gases react with carbon to form carbon dioxide, which diffuses in the opposite direction. Without further discussing the possibility of such a diffusion process, it may merely be stated that the diffusion of the oxygen into the iron must under all circumstances occur very slowly, as the solubility of oxygen in iron at the temperature concerned (about 1000° C.) can be only some hundredths of one per cent. As the solubility of carbon in γ-iron is about 1·5% and as, owing to its lower atomic weight, its diffusion coefficient may be expected to be smaller than that of oxygen, there is no need, when calculating the rate of decarburisation, to take into account anything but the diffusion of carbon (*see* below).

The diffusion rate should be proportional to the decrease of concentration per unit length in the austenite phase. It is thus of great importance that the carbon content in the surface layer be kept as low as possible. The carbon content of the surface depends partly on the rate of the reaction between the carbon and the carbon dioxide of the gas at the surface, and partly on the rate at which the carbon monoxide formed is removed from the surface by diffusion and convection and replaced by new carbon dioxide. It is possible, besides, that the nature of the surface of the grains may influence the progress, especially under the conditions prevailing in practice.

If the supposition is made that the carbon content of the grain surface adjusts itself to be in equilibrium with the carbon monoxide and dioxide of the gas mixture introduced, the rate of decarburisation can, under certain assumptions, be calculated approximately by the application of equations formulated by Dünwald and Wagner.[1] With these equations it is possible to calculate the time required for

[1] *Zeitschrift für physikalische Chemie*, 1934, *B*, vol. 24, p. 53.

reducing to a certain value, by diffusion, the average content of an element dissolved in a solid body. If the body is spherical, the following approximate equation may be used :

$$\frac{C_m - C_i}{C_b - C_i} = \frac{6}{\pi^2} \cdot e^{\frac{\pi^2 D}{R^2} t} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

provided that :

$$t > \frac{R^2}{2\pi^2 D} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where :

C_b = the initial concentration of the diffusing element.
C_i = the constant concentration of this element supposed to be reached immediately at the surface of the body.
C_m = the average concentration dependent on the time.
t = the time during which the diffusion has been proceeding.
R = the radius of the spherical solid body.
D = the diffusion coefficient.

In order to be able to apply the above formula to the decarburisation process it is necessary to know the diffusion coefficient. According to determinations recently published by R. F. Mehl [1] and his co-workers, the diffusion coefficient for carbon in austenite, in unalloyed iron, at 1000° C. seems to be :

$$D = 3{\cdot}7 \cdot 10^{-7} \text{ sq. cm. per sec.}$$

This value has proved to be only slightly dependent on the carbon content.

The equation holds true only on the condition that the diffusing element is dissolved in the metal. However, at the beginning of the decarburisation the main part of the carbon is present in the form of cementite or graphite, and only a smaller part is dissolved in the austenite, the solubility of graphite in austenite at 1000° C. being about 1·5%. Thus the equation cannot be used for exact calculations of the decarburisation rate if the initial carbon content exceeds about 1·5%. If a calculation is made under the assumption that the initial carbon content is 1·5% and the equilibrium content 0·02%, it will be found that the average carbon content in a spherical grain of 3 mm. diameter is dependent on the time of decarburisation in the following manner :

Time of decarburisation. Hr. .	1	2	4	8
Carbon content. % . .	0·50	0·30	0·11	0·03

According to the equation *the time of decarburisation is*, further, *proportional to the square of the radius of the grain.* If in the above example the diameter is presumed to be 1·5 mm. instead of 3 mm., a carbon content of 0·50% is obtained after 15 min. only and of 0·03% after 2 hr.

A number of laboratory tests have been made in order to

[1] R. F. Mehl, American Society for Metals, Oct., 1938, Preprint No. 25.

ascertain what rate of decarburisation can be reckoned with in practice under favourable conditions.[1] The tests consisted in heating the granulated iron in a small rotary furnace of quartz glass through which the gas was allowed to stream continuously.[2] In one case nearly round grains of approximately the same size, 1·5 mm. in dia., were used. The grains, which had low silicon and manganese contents, were decarburised at 1000° C. in the following gas mixture :

CO_2 8·4%; CO 23·0%; H_2 43·2%; H_2O 25·4%.

A curve showing the decrease of the residual carbon with time is reproduced in Fig. 3.

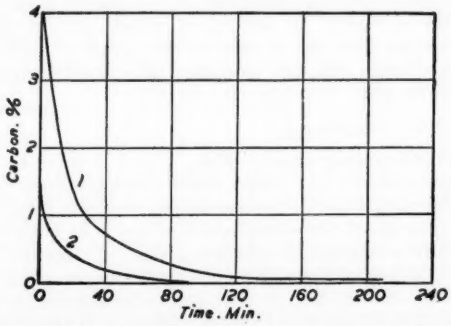


FIG. 3.—Rate of Decarburisation Obtained on Relatively Round Grains about 1·5 mm. in dia. (curve 1) in comparison with maximum rate calculated for 1·5-mm. grains at an initial carbon content of 1·5% (curve 2).

For comparison, a curve has also been traced that shows the carbon content calculated in the way mentioned above. The initial carbon content has been assumed to be 1·5%. In these tests the rate of decarburisation is somewhat below the maximum rate calculated; for instance, the carbon content has decreased from 1·5% to 0·25% in 60 min. as against the calculated time of 40 min. It should, however, be pointed out that the decarburisation, beginning with an average carbon content of, say, 1·5%, will occur more rapidly if the initial carbon content is higher, because in the latter case the carbon would be higher in the centre than at the surface when the average content of 1·5% is reached. The difference in the rates of decarburisation is, consequently, actually smaller than a direct comparison of the curves indicates. Under favourable

[1] B. Kalling and I. Rennerfelt, *Jernkonterets Annaler*, 1939, vol. 123, p. 115.

[2] B. Kalling and J. Stålhed, *Jernkontorets Annaler*, 1937, vol. 121, p. 30.

conditions the rate of decarburisation, therefore, does not differ to any great extent from the maximum rate calculated theoretically.

Consequently, any important slowing down of the process due to reduced velocity of the reactions at the surface need not be feared at a temperature of 1000° C. On the other hand, the gas composition close to the surface of the grain, and therefore also the rate of decarburisation, must be influenced to a great extent by the rate at which the carbon dioxide formed is carried away from the place of reaction. This circumstance must be considered if the process is applied in practice.

The temperature has a great influence, not only on the equilibrium but also on the rate of decarburisation. An increase in temperature results in a higher diffusion coefficient of the carbon as well as in an increase of its solubility in austenite, which also promotes the diffusion. Besides, the rate of reaction is increased at the surface, though, in accordance with the foregoing, this circumstance does not seem to have any great importance normally.

Influence of Alloy Constituents.

The equilibrium diagrams in Figs. 1 and 2 refer to iron containing carbon without any other alloy constituents. The silicon and manganese contents of commercial pig iron can, however, cause considerable changes in the equilibrium ratios. As both silicon and manganese have a considerably higher affinity to oxygen than iron, the presence of either of these elements must always cause a decrease of the content of carbon dioxide that can be present in the gas phase without oxidation of the metal also occurring. If the alloy content exceeds a certain limit, it should no longer be possible to carry out the decarburisation without the metal oxidising simultaneously. If the oxidation of, say, a siliceous pig iron takes place, it is, however, the silicon that is oxidised in the first place, whereas the oxidation of iron will be inconsiderable, as long as the carbon-dioxide content of the gas does not exceed the limiting value of the pure Fe–C–O system. The silicon in the surface layer will in this way be successively diminished to a value that approaches equilibrium with the surrounding gas phase, after which the continued attack will be dependent on the rate at which silicon diffuses out to the surface from the interior of the iron grain. Thus, both carbon and silicon diffuse towards the surface, but as silicon, on account of its higher atomic weight, diffuses considerably more slowly, the possibility arises of decarburising even a siliceous pig iron in a carbon-dioxide/carbon-monoxide atmosphere without any appreciable oxidation of the metal and with a CO_2 : CO ratio that is very nearly as high as that for an iron free from silicon. Manganese behaves in the same way. The thin oxide film formed can, however, cause a deterioration of the contact between the gas phase and the metal and thereby impede the decarburisation.

In order to ascertain what influence the silicon and manganese of the pig iron can have in practice on the rate of decarburisation, some test series have been carried out with pig irons of various silicon and manganese contents. The tests show a rate of decarburisation successively decreased with increased silicon though the influence is insignificant as long as the silicon content does not exceed about 1%. Manganese contents up to 2·5%, on the other hand, do not seem to have any influence at all. The cause of the retardation of the decarburisation with increase of silicon content may be that the oxide film formed on the surface becomes progressively less permeable to the oxidising gases, causing a slower rate of decarburisation. Manganese, on the other hand, does not seem to produce any such passivifying oxide film.

Even if it has not been possible by means of the various tests fully to explain the influence of the alloy constituents on the rate of decarburisation, the results still show that the decarburisation of pig iron with up to about 1·5% of silicon and 2·5% of manganese can be carried out at a rate quite satisfactory from a technical viewpoint, and down to very low carbon contents.

Change of Structure during Decarburisation.

Only one observation will be made here: When decarburising siliceous and manganiferous pig iron down to low carbon contents, there is, as previously indicated, always some oxidation also of the metal, leading to the formation of an oxide film, which may, however, be extremely thin. At the same time, a certain degree of oxidation occurs also under the surface, which manifests itself in the formation of oxidic slag inclusions in a zone next to the surface. These inclusions are evidently formed by a reaction between the silicon and manganese contained in the metal and oxygen, the latter diffusing inwards from the surface. On account of the low diffusion rate of oxygen, this zone, however, is normally only of a very small depth, say, approximately 0·01 mm. after a very far-reaching decarburisation of a grain 1·5 mm. in dia. at about 1000° C.

In the slag-containing zone, which is very clearly distinguished from the inner metal low in slag, the slag inclusions seem to be evenly distributed in regard to both their amount and their size. No distinct gradient towards the surface can be observed. This is easily understood, as the solubility of oxygen in a siliceous and manganiferous iron is extremely low. Thus, the oxygen cannot penetrate further until practically all the silicon and manganese are oxidised at the depth to which the oxygen has reached at any given stage. In the slag zone, the slag inclusions should, therefore, contain practically all the silicon and manganese of the metal in this zone. The inclusions can, further, contain a certain amount of ferrous oxide, which, however, will be liable to increase as long as its activity is less than that of the ferrous oxide at the surface of the grain.

An example of the extension of the slag zone in a grain will be

seen in Fig. 9. The appearance of the slag particles is more clearly to be seen in Fig. 10, which shows the surface of the same grain at a larger magnification.

Technical Tests.

Tests at Avesta.

Everything pointed to the rotary furnace being the most appropriate type of furnace for carrying out the decarburisation. By the courtesy of the Avesta Jernverks Aktiebolag, facilities were provided to make the first experiments in a rotary furnace at their plant at Avesta. The furnace had an inner diameter of 800 mm. and an inner length of 2500 mm. The furnace was provided with means for heating of charge electrically. The charge itself formed the resistance to the electric current, which passed through the charge between electrodes of heat-resisting steel.

After some preliminary trials, the process in this furnace was first carried out in such a way that the charge, being fed continuously through the furnace, was heated to about 1000° C. by means of the electric current. The requisite oxidising atmosphere was obtained by introducing a blast pipe through the central feeding opening.

In this way a satisfactory rate of decarburisation was obtainable, and it was established that the reaction gas formed could be completely burned above the charge without any surface oxidation of the granulated iron taking place. This proved the possibility of rationally utilising the carbon content of the granulated iron as a fuel for carrying out the process.

On the other hand, the current supply was interfered with by the introduction of air, the cause of which will not be dwelt upon here. The idea then arose of carrying out the process without the use of electric current. It was found that a great part of the heat required could be supplied by the combustion of the reaction gas, and the balance might be covered by adding some other fuel in place of electric current. Arrangements were therefore made for the introduction of oil.

A short period of operation with oil as an additional fuel gave favourable results. At a feeding rate of 100 kg. of granulated iron per hr., an amount of oil equivalent to only about 2% of the output was required to keep the temperature at the level desired. At this feeding rate the carbon content was reduced to about 0·5% in the product. It seemed that the process could be carried out without any serious disturbances, but nevertheless some changes in the design of the furnace were found desirable.

As it was considered to be of special importance to ascertain whether blast-furnace gas could be used as an additional fuel instead of oil, corresponding arrangements were made. Further, the furnace was lengthened, to an inner length of 3·4 m. (Fig. 4). Gas and air were introduced into the furnace at the feeding end through two concentric pipes of heat-resisting steel. The gas was conducted

through the inner and the air through the outer pipe. Along the latter were a number of outlets, so as to obtain progressive combustion of the reaction gas and the added blast-furnace gas during their passage through the furnace in the opposite direction to the flow of the material. After leaving the furnace, the granulated iron was cooled in the sluicing drum shown to the right of the drawing. This drum was divided in sections by a number of transverse steel plates, each with an opening along the periphery (*see* Fig. 7). The openings were placed so that one of them was always completely covered by the material. This arrangement made it possible to discharge material during the rotation of the drum, and

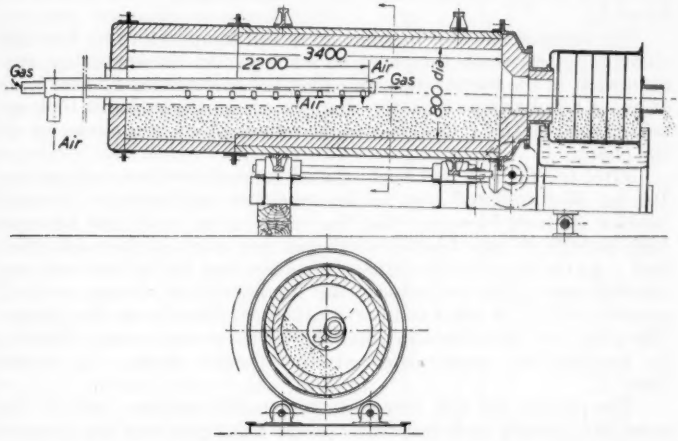


FIG. 4.—The Experimental Furnace at Avesta.

at the same time to prevent the gas from escaping through the same opening.

The furnace was lined with a 100-mm. layer of ordinary firebricks, surrounded by a 50-mm. layer of insulating bricks.

The longitudinal inclination of the furnace was 2·5%, and the speed of rotation was 2·5 r.p.m.

The granulated iron used during the experiments was obtained partly from the Wikmanshytte Bruks Aktiebolag, Wikmanshyttan, and partly from the Laxå Bruks Aktiebolag, Laxå. The material from Wikmanshyttan was produced by granulation in water by the method for long practised at this works (*see* below). The Laxå granulated iron was produced by subjecting the molten iron to the action of a steam jet. Tests were also made with crushed pig iron

from Laxå, obtained by crushing coarser granulated pig iron. Grains above 5 mm. in size were sifted out in all cases.

The chemical analyses, specific gravities and sift analyses of the materials used are given in Table I.

The blast-furnace gas normally contained about 12% of carbon dioxide, about 25% of carbon monoxide and about 4% of hydrogen. The amount of air and gas was regulated by simple dampers. The distribution of the air in the furnace was regulated by stopping up some of the air outlets. In addition, an air outlet of the same size as the other ones was placed at the inner end of the pipe, whereby a certain quantity of air was also introduced parallel to the gas, partly burning it. In this manner, a certain amount of heat was generated also at the discharge end of the furnace, which proved to be useful.

The furnace was first brought up to full temperature by burning charcoal, after which the charging started. At the beginning, the air outlets of the burner pipe were directed towards the furnace wall at about a right angle from the charge in the position that it took up during the rotation; the idea was to reduce the risk of oxidation of the charge.

After the furnace had been started running continuously, about 100 kg. of granulated iron per hr. were first fed through. It soon became evident, however, that the temperature could not be kept high enough if only blast-furnace gas was used as the additional fuel. As the flame in the furnace was only very feebly luminous, an attempt was made to increase the luminosity by adding a small quantity of oil, in order to improve the heat transfer to the charge. The effect was that intended, and there was no longer any difficulty in keeping the temperature at the desired level, *i.e.*, about 1000° C.

The process did not, however, work satisfactorily. Part of the most fine-grained material stuck to the brick joints of the furnace wall, and these sinterings had a strong tendency to grow by the continued adhesion of fine-grained material. A closer study of the coatings during the operation showed that they had a considerably higher temperature than both the furnace wall and the charge, and this explained their tendency to grow. The cause of the increase in temperature must have been that combustion of the iron took place with *free* oxygen. It is true that oxidation of iron can occur also with carbon dioxide, but as this reaction takes place without any appreciable change of heat, it cannot cause any inconvenient increase in temperature.

A prime condition was, therefore, to prevent the occurrence of an excess of air in the furnace close to the furnace wall. The amount of gas must, then, be so ample and the combustion take place so rapidly that only combustion gases free from oxygen pass along the furnace wall. The rather radical change was then made that the burner pipe was turned through 180° and the air in this way was

directed straight towards the charge instead of towards the furnace wall. The result was that the coating ceased immediately. At the same time, the heat transfer to the charge was so greatly improved that there was no difficulty in keeping the temperature sufficiently high without any addition of oil. At the same time, the wall temperature diminished in relation to that of the charge. The temperature in the hottest zone during continued operation was kept at about 1000–1050° C.

Any increased tendency to the oxidation of iron also because of the changed mode of operation could not be observed. Samples of the granulated iron, taken in the hottest zone, proved to be still uncoloured if the cooling took place without the admission of air.

The escaping gases during normal operation proved in general to be free from free oxygen, but at the same time also nearly free from unburnt carbon monoxide. The content of carbon dioxide after complete combustion was about 21%. The temperature of the escaping gas was high; a determination gave 700° C.

The feeding rate was varied between 100 and 200 kg. per hr. The weight of the charge in the furnace was about 1500 kg. of granulated iron, and the total time of treatment was thus between 7·5 and 15 hr. As the reaction temperature was not reached until about the middle of the furnace, the main decarburisation took place within a time interval of only 3·5–7 hr.

As was to be expected, both the feeding rate and the temperature proved to have a great influence

TABLE I.—*Chemical Analyses, Specific Gravities and Sieve Analyses of the Materials Used.*

Sample of granulated Pig Iron from—	Chemical Analysis.						Specific Gravity.	Sieve Analysis. %.					
	Carbon. %.	Iron. %.	Manganese. %.	Silicon. %.	Phosphorus. %.	Sulphur. %.		4 mm.	4–2 mm.	2–1 mm.	1–0·5 mm.	0·5–0·2 mm.	<0·2 mm.
I. Laxå, ordinary	4·15	95·3	0·14	0·42	0·052	0·008	3·67	0·5	41·0	37·5	8·0	11·5	1·5
II. ,, finely grained	4·20	95·2	0·13	0·42	0·056	0·006/7	4·14	0·5	12·0	30·5	16·5	32·0	8·5
III. ,, crushed	4·28	95·3	0·15	0·27	0·062	0·006	3·66	2·0	49·5	39·0	5·5	3·5	0·5
IV. Wikmanshyttan	4·22	95·0	0·24	0·55	0·036	0·006	4·16	0·5	22·0	35·0	12·5	22·5	7·5

on the carbon content of the product. The relation proved to be approximately as follows :

Carbon Content at Different Rates of Feeding and Temperature.

	980° C.	1040° C.
100 kg. per hr. . .	About 0·25	About 0·03
200 kg. per hr. . .	About 1·00	About 1·25–0·50

On leaving the sluice, the granulated iron was always slightly oxidised on the surface, because it had not been completely protected against oxidation during the cooling in the sluice. When making a material with a low carbon content, below about 0·10%, it was also difficult to prevent slight surface oxidation within the furnace.

TABLE II.—*Data from the Experimental Operation, 23–30 April, 1937.*

Date.	Time.*	Charged—		Average Temp. of Grains in Hottest Zone. ° C.	Discharged—		Notes.
		Grains. Kg.	Petrol. Litres.		Grains. Kg.	Approx. Carbon. %.	
		(1) *Blast Nozzles Turned from the Charge towards the Wall.*					
23/4	11–24	2000	21·5	970	...	...	Laxå granulated iron.
24/4	0–12	1200	18	980	930	0·80	
	12–24	1200	16·5	980	721	0·30	
25/4	0–12	2300	10	965	2192	0·25	
		(2) *Blast Nozzles Turned towards the Charge.*					
25/4	12–24	1450	...	980	1752	1·00	
26/4	0–12	1200	...	990	1108	0·20	
	12–24	1150	...	1000	1181	0·10	
27/4	0–12	1200	...	1030	1103	0·05	
	12–24	1200	...	1050	1249	0·04	
28/4	0–12	1250	...	1040	1231	0·03	From 11 o'clock crushed Laxå grains.
	12–24	1450	...	1040	1368	0·08	
29/4	0–12	1900	...	1045	2025	0·06	
	12–24	2300	...	1040	1962	0·10	From 16 o'clock Wikmanshytte granulated iron.
30/4	0–12	2400	...	1010	2356	0·05–0·80	
	12–18	836	...	980	1045	0·07–0·50	From 12 o'clock relatively fine Laxå grains.

* On the twenty-four-hour clock.

For somewhat more than 24 hours a trial was made with a crushed granulated iron. This product did not prove so suitable for the process as granulated iron in its original state. The sharp-edged grains hooked into one another, and the charge did not flow so evenly in the furnace. The angle of slip of the charge increased and at the highest temperature, about 1050° C., it amounted to nearly 90°. Though the process, especially with an appropriately selected analysis of the pig iron, can also be carried out with a crushed product, the more rounded grains of granulated iron are decidedly to be preferred.

The furnace was kept in continuous operation for seven days, during which time the available quantity of granulated material was decarburised. The only real standstill was the period of about 30 min. that was required for the above-mentioned change of the

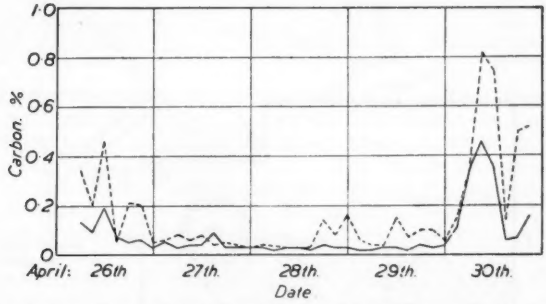


FIG. 5.—Carbon Contents Obtained During the Experimental Operation at Avesta. The full curve represents grains smaller than 2 mm. and the dotted curve grains larger than 2 mm. in dia.

air supply. Any damage or wear on the furnace caused by the operation could not be observed.

No direct measurement was made of the amount of blast-furnace gas used. It was, however, possible to get an idea of this amount from a calculation based on analyses made on the escaping gas. This calculation gave a gas consumption of about 300 cu. m. per ton at a rate of feeding of 100 kg. per hr., and of 150 cu. m. at a feeding rate of 200 kg. This gas quantity is unimportant from an economical point of view. Still, there was reason to believe that it could be considerably reduced or possibly wholly dispensed with in a larger furnace, constructed with an improved heat economy in view (*see* below).

A summary of the operation results is given in Table II., and all the analyses from the last days are found in Fig. 5. Before analysis, the samples were divided into two grain classes, above and below 2 mm., which were analysed separately.

Experiments at Fagersta.

On account of the favourable results obtained in the trial operation at Avesta, the Fagersta Bruks Aktiebolag decided to install a plant on a fully technical scale. As the question of the best way to granulate the pig iron in order to get a product of the desired size and form of grain had not yet been thoroughly investigated, some granulation trials were first made at Fagersta by different methods. The main question was to get all the iron transformed into grains of

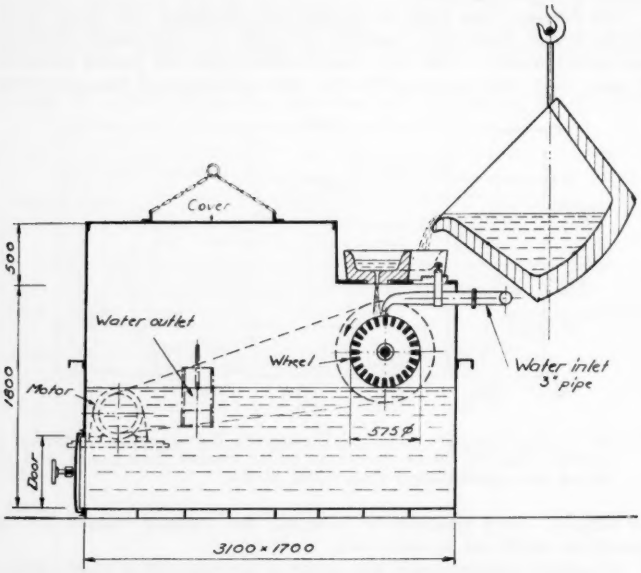


FIG. 6.—The Granulation Equipment at Fagersta.

smaller diameter than the maximum desired for the decarburisation process. A further aim was to get the grains as round as possible. The tests proved that the principle previously applied at Wikmanshyttan and also at other places might be expected to yield so good results, that little was to be gained, at least for the time being, by changing to some other method.

Fig. 6 shows in principle the granulation plant that was then built at Fagersta. As shown by the drawing, the pig iron is poured from a ladle into a small container, provided with a hole of suitable section in the bottom. Through this hole the pig iron passes down in a thin jet towards a rotating drum, provided with strips of wood,

which shatter the jet and throw the pig iron drops down into the water basin, where they are cooled. In order to keep the wood shovels moist all the time and to prevent their destruction, an ample quantity of water is flushed on the wheel immediately before the iron strikes it. The total quantity of water required for the granulation depends in the first place on the temperature allowed for the water leaving the apparatus. The water supply was generally so regulated that the temperature in the basin rose to about 70° C. during the granulation. About 5 tons of pig iron are granulated at a time, at a rate of about 200 kg. per min. This rate can, however, be considerably increased, if desired, without any great changes being necessary. In the operation at Fagersta granulated pig iron of chiefly the following analysis has been used :

	I.	II.
Carbon. % . . .	About 4·5	About 4·3
Silicon. % . . .	„ 0·50	„ 0·20
Manganese. % . . .	„ 1·25	„ 0·35
Phosphorus. % . .	Max. 0·025	Max. 0·025
Sulphur. % . . .	„ 0·010	„ 0·015

Both types have proved to granulate well, but the analysis has a great influence on the behaviour of the iron during the granulation. A high silicon content, for instance, tends to render the grains, especially the coarser ones, hollow. This can be an advantage, as the coarser grains, which otherwise require the longest time of decarburisation, are hereby more rapidly decarburised. If, on account of composition or temperature, the iron is viscous when being tapped, it may be difficult to get round grains. The product is obtained in the form of flattened grains or flakes, which fact depends on the grains not having had time to assume a more rounded form before solidifying.

The chief purpose of the experiments at Fagersta was to produce a decarburised iron with the lowest possible carbon content. A fine-grained material was therefore desired, and proved to be obtainable without any great difficulty.

After the problem of granulation had been satisfactorily solved, a decarburisation furnace intended for a production of 6–10 tons per 24 hr., was erected. Fig. 11 shows a photograph of the furnace seen from the feeding end, and Fig. 7 is a longitudinal section. The furnace has an inner diameter of 1050 mm. and an inner length of 4000 mm. The brick lining is 225 mm. thick and consists of an outer layer of insulating bricks 115 mm. thick and inside of this a 110-mm. layer of firebricks. The diameter of the inlet opening is 350 mm. and of the outlet opening 250 mm. The latter is connected with a sluice, constructed on the same principle as that of the Avesta furnace. The longitudinal inclination of the furnace, which is adjustable, has hitherto been about 3%.

The design of the burner was altered somewhat in order to provide better regulation. It consists of three concentric pipes,

which for the parts exposed to high temperature are made of a heat-resisting iron-chromium-nickel alloy. The two inner pipes are open, whereas the outermost pipe is closed at the end but is furnished with a number of openings along its length, exactly as on the Avesta furnace. Through the innermost pipe blast-furnace gas is introduced. This gas is partly burned with " primary air," which is introduced through the middle pipe and the amount of which can be regulated. The " secondary air," which is supplied through the nozzles of the outermost pipe at approximately right angles to the charge, brings about the main decarburisation here, and at the same time burns the main part of the carbon monoxide of the furnace gas into carbon dioxide before leaving the furnace.

The burner and the blower, which is common to the primary and the secondary air, are, as shown in Fig. 7, suspended on wheels running on a beam, by which arrangement the position of the burner can easily be adjusted and, also, the whole burner can easily be pulled out from the furnace without turning off the air. The blast-furnace gas is supplied through a pipe that can be adjusted axially within the burner pipe, thereby allowing small changes of the position of the burner to be made without shutting off the gas.

The speed of rotation of the furnace has hitherto mostly been about 3 r.p.m.

From the first the operation of the furnace could be kept up without any appreciable disturbances. A temperature of 1050° C. has proved to be appropriate in the hottest zone, *i.e.*, at the innermost nozzle for the secondary air. The temperature is controlled by means of an optical pyrometer. It has proved expedient to regulate the amount of primary air in such a way that the temperature decreases somewhat towards the discharge end. If too much primary air is admitted, there is a risk of oxidation of the iron also in this zone, as the main part of the carbon has already been eliminated at this place.

During most of the time the output has hitherto been only 6–7 tons per 24 hr., corresponding to rather more than would fill the furnace once. At this rate of operation there has been no difficulty in keeping the average carbon content of the product below 0·10%, and during certain periods it has been below 0·05%. Operation with more rapid feeding has also been tried. At a feeding rate of up to 10 tons per 24 hr. the carbon content could still be kept down to 0·10%. However, when the feeding rate was increased to 13 tons, the carbon values became irregular and rose considerably above 0·10%; this seemed partly to be caused by the air supply being too small.

As mentioned above, the operation at Fagersta has hitherto had in view primarily the production of a material with the lowest possible carbon content. Because the decarburisation becomes more difficult as the grains become coarser, the carbon content with rapid feeding has generally been substantially higher in the coarser

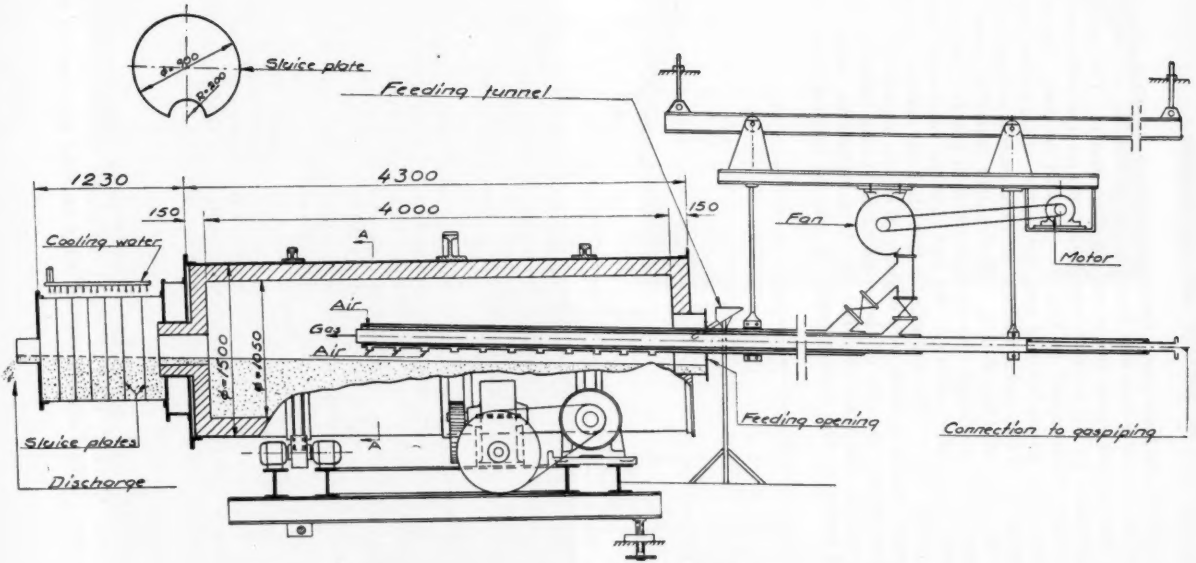


FIG. 7.—Longitudinal Section of the Fagersta Decarburisation Furnace.

grains than in the finer ones. On some occasions, however, the carbon content in coarse grains was found to be as low as, or even lower than, that in finer grains taken out simultaneously. The conditions are illustrated by the series of analyses from an operating period of eleven days summarised in Fig. 8. As will be seen, the carbon contents of the grains below 2 mm. are on the whole rather uniform, just as in the Avesta tests, and the average carbon content of these grains is not more than 0·03%. The coarser material varies more in carbon content, though the variation will in practice be less than the analyses indicate, owing to the fact that the values are based on a few grains only. The remarkable fact that the carbon content of the coarser grains is often very slightly, if at all, higher than that of the finer grains, in spite of the established strong influence of the grain size on the time required for decarburisation, seems to be caused partly by the coarser grains in general keeping more closely

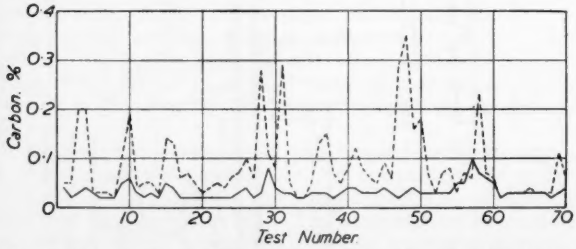


FIG. 8.—Carbon Contents Obtained During an Operation Period of about 14 Days at Fagersta. The full curve represents grains smaller than 2 mm., and the dotted curve grains larger than 2 mm. in dia.

to the surface during the rotation than the small ones, thereby being exposed to a stronger oxidising atmosphere. Another cause seems to be that the finer grains pass through the furnace somewhat faster than the coarser ones. The average value for the grains above 2 mm. is 0·09%. The total average analysis during the time of operation was 0·05%. According to the experience at Fagersta, it will be possible to keep the average carbon content constantly below 0·05%, provided that the output is properly adapted to the dimensions of the furnace and to the grain size of the granulated iron.

The Fagersta furnace is now used in continuous operation for producing a charging material low in carbon for the production of high-quality steel in open-hearth and electric steel furnaces.

Other Installations.

Besides that at Fagersta, there is still another furnace in operation in Sweden, namely, that at the Uddeholms Aktiebolag Hagfors Steelworks. This furnace, started some months ago, has an inner

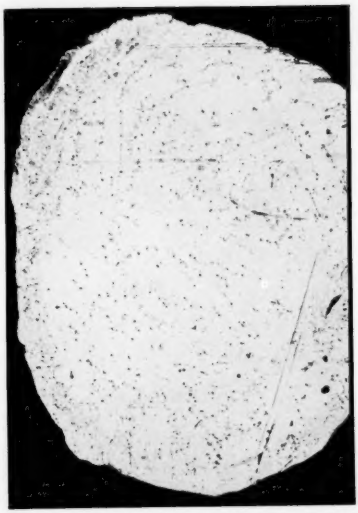


FIG. 9.—Unetched Section of a Nearly Completely Decarburised Grain. × 50.

FIG. 10.—Detail of the Section in Fig. 9 at a Higher Magnification. × 500.

(Micrographs reduced to two-thirds linear in reproduction.

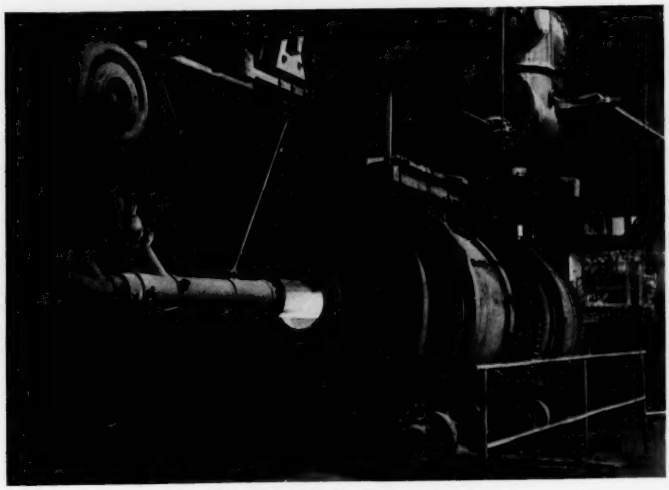


FIG. 11.—The Decarburisation Furnace at Fagersta.

[*Bo Kalling and Rennerfelt.*

[*To face p.* 156 P.

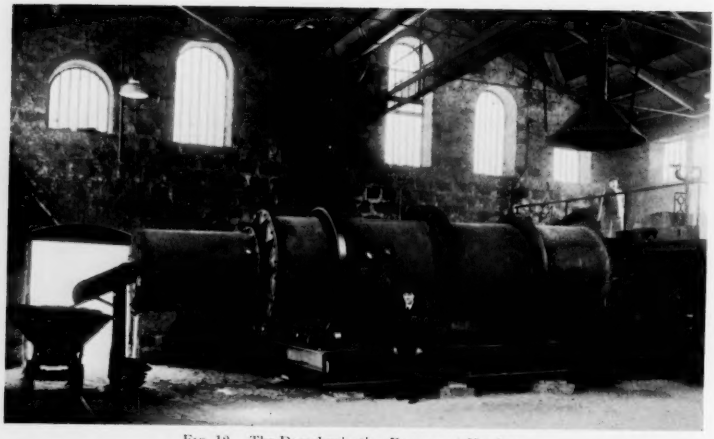


FIG. 12.—The Decarburisation Furnace at Hagfors.

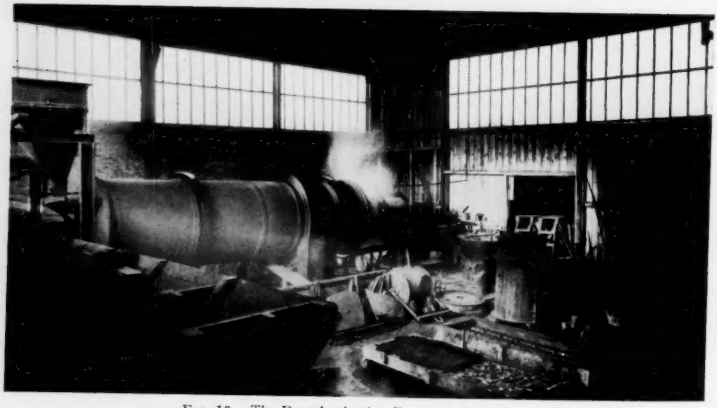


FIG. 13.—The Decarburisation Furnace at Imatra.

[*Bo Kalling and Rennerfelt.*
[*To face p.* 157 P.

length of 6000 mm. and an inner diameter of 1200 mm. It is designed for a production of 12–20 tons per 24 hr. with a carbon content of 0·05–0·50% in the final product. Some information on this equipment has been given by E. Fornander and C. von Delwig at the Technical Meeting of Jernkontoret this year.[1] A photograph of the furnace, Fig. 12, has kindly been placed at the authors' disposal. The furnace is, on the whole, constructed on the same principle as the Fagersta furnace, though with certain modifications, depending among other things on the local conditions. The additional fuel in this case consists of gas from an electric pig-iron furnace instead of blast-furnace gas.

The method has also gained a footing outside Sweden. At the Vuoksenniska Aktiebolag Imatra Steelworks a furnace of about the same size as the Hagfors furnace is already in operation. Though the furnace has hitherto been in continuous operation for only a short time, the results, as the management have kindly informed the authors, have already proved that a production of 20 tons per 24 hr. will be obtainable without difficulty at a final carbon content of about 0·40%. A product with less than 0·05% of carbon is placed on the market. A picture of this furnace is given in Fig. 13.

Also in other countries introduction of the method has been decided upon, though the plants have not yet been erected.

Summarising Views on the Carrying-Out of the Process.

At the furnaces hitherto erected it has proved necessary, or at any rate desirable, to add a certain amount of blast-furnace gas or some other fuel, though the requisite quantity has no great economic importance. The object of the additional fuel is in the first place to regulate the oxidising influence of the furnace gases in different parts of the furnace. Especially when refining down to very low carbon contents, the gas will tend to become too strongly oxidising at the outlet end if no reducing gas is added. If, however, the carbon content is not to be reduced so far, it will be at least theoretically possible to shut off the gas supply completely, because the risk of oxidation of the iron becomes less as the remaining carbon content becomes higher. It has also been established that under certain conditions the furnace can be operated practically without any gas supply, *i.e.*, the process is run practically as a Bessemer process. That the carbon content of the charge can really suffice both for its heating and to cover the heat losses is evident from the heat balance given in Table III. However, if no additional fuel at all is used, there is a great risk of an excess of oxygen occurring at some point, causing a tendency to sintering. With the present construction of the furnace a certain addition of

[1] Not yet published.

gas is consequently always desirable in order to improve the reliability in operation.

TABLE III.—*Heat Balance of Decarburisation per* 1000 *Kg. of Decarburised Product.*

Production	600 kg. per hr. (about 15 tons per 24 hr.)
Carbon content of pig iron . .	4·2%
,, ,, ,, product . .	0·5%
Temperature of granulated iron on leaving furnace	1000° C.
Temperature of escaping gas. .	400° C.
Composition of escaping gas: 21% of CO_2 and 79% of N_2. The blast is presumed not to be preheated.	

Heat Introduced.	Kg.cal.
$Fe_3C \longrightarrow 3Fe + C$ (graphite); 38 kg. of carbon at 290 kg.cal. .	11,000
C (graphite) $\longrightarrow CO_2$; 38 kg. of carbon at 7830 kg.cal. . .	298,000
Total	309,000

Heat Escaping.	
Heat in 1000 kg. of product at 1000° C. at 165 kg.cal. . .	165,000
,, 128·5 kg. of CO_2 at 400° C. 3·14 mol. at 4,085 kg.cal..	12,800
,, 308 kg. of N_2 at 400° C. 11·95 mol. at 2,867 kg.cal. .	34,200
Total	212,000

Excess for covering radiation losses. 309,000 − 212,000 = 97,000
At a production of 600 kg. per hr. this excess corresponds to a heat quantity of 58,000 kg.cal. per hr. (= 68 kW.).

The pig-iron analysis to be chosen depends in the first place on the requirements of the consumer of the product. As regards the silicon content, it has, as mentioned above, only a slightly retarding influence on the decarburisation process in amounts up to about 1%, and higher contents will seldom be required in the product. As a rule, a relatively low silicon content will be desired, especially if the granulated iron is to be remelted in basic processes.

The manganese content can be chosen within wide limits without the course of the process being appreciably influenced.

The selection of an appropriate grain size is, as pointed out previously, of the utmost importance to the working of the process. The rate of decarburisation and with it the output diminish rapidly with increased grain diameter, and on account hereof the grain size should not be allowed to be too large. On the other hand, it is desirable from the consumer's point of view that the granulated iron should be not too fine-grained. The decarburisation furnace should, therefore, be large enough so that even relatively large grains have time to be decarburised sufficiently at the output intended. An appropriate upper limit to the grain size will be about 10 mm. When making material of low carbon content, for instance, below 0·05%, the upper limit should be lower, say, about 5 mm.

In this connection perhaps the fact warrants mention that it is not necessary to force down the carbon content of the grains to, say, 0·03% in order to obtain this carbon content in the steel made in the following steel melting process. When producing material with low carbon content, the grains in the normal course of the process become somewhat oxidised on the surface. When the material is then heated again in the melting furnace, the oxide present causes some further carbon to be removed before fusion occurs. Melting tests made have shown, for instance, that the carbon content can be reduced from about 0·10% and probably more in the grains to between 0·02 and 0·03% in the molten bath.

Cost of the Process.

It is not the intention to present any calculation of costs here. Only a few points will be stated.

As the decarburisation is done with gaseous oxygen, an unavoidable loss results during the process, corresponding to the carbon content removed, *i.e.*, normally about 4%. On decarburisation to very low carbon contents there is, besides, always some oxidation of the other constituents of the material to be considered, in the first place of silicon and manganese. In granulation there seems to be no risk of any appreciable loss of material.

As appears from the foregoing, the amount of additional fuel possibly required for the process is insignificant.

Wages will be low if the production is not too small. It will be possible to mechanise the operation without difficulty, so that the manual labour will mainly be limited to the control of the furnace and its accessories.

The cost of repairs should also be low, among other things on account of the relatively low operating temperature.

As, in addition, the capital required for erecting a decarburisation unit of this type will be rather modest, the product can be obtained at a cost which has been proved to render its use as a raw material for the manufacture of steel economically advantageous under certain conditions.

Use of the Product.

Decarburised granulated iron is, in the first place, intended to fill the need of a low-carbon material of known and constant composition and of known origin as a raw material for the manufacture of high-quality steel. It seems to become more and more difficult to obtain scrap that is sufficiently free from the usual alloy constituents, such as chromium, nickel and copper, besides which there is always the risk of its containing also other, unknown, impurities which may influence the quality. The product will have a field of use particularly in such processes where no appreciable decarburisation usually takes place, such as the electric and crucible steelmaking processes.

For the acid processes it is, of course, necessary that the granulated product be made from a pig iron sufficiently low in sulphur and phosphorus. For the basic processes it will also be possible to use granulated iron made from ordinary coke pig iron for the production of a material with specific requirements.

The possibility of reducing the carbon content of the granulated iron to particularly low values before and during melting seems, besides, to open a not unimportant field of application in the production of alloy steels with low carbon contents.

The authors suppose that it is too early to answer definitely the question whether the "R.K." process may also become of importance as a decarburising method for the manufacture of ordinary qualities of steel in competition with other methods. It does not, however, seem quite impossible. The yield is higher than that of the Bessemer process and the conversion costs for a large output would be low. The decided disadvantage of the method, namely, that the material is not obtained in the molten state, is to some extent counteracted by the fact that no apparatus corresponding to the mixer is required to keep the iron hot. In comparison with, say, a duplex process, in which the Bessemer converter is used for a preliminary treatment, it is therefore not impossible that the "R.K." process will under certain conditions prove advantageous. The higher nitrogen content in the steel produced by the Bessemer process should be kept in mind in this connection.

In cases where the pig iron cannot be directly converted into steel, for instance, if the blast-furnace is situated at a long distance from the steel plant and any hot-metal process cannot, consequently, be considered, the advantages of the "R.K." process become more distinct.

In the case of new plants, the simplicity of the method and the low costs of building are especially advantageous.

THE EFFECT OF CASTING TEMPERATURE ON THE PRIMARY MICROSTRUCTURE OF CAST IRONS.

THEORIES OF DENDRITE FORMATION AND OF THE SOLIDIFICATION OF IRON-CARBON ALLOYS.[1]

By A. L. NORBURY, D.Sc. (British Cast Iron Research Association, Birmingham).

(Figs. 1 to 56=Plates XXIII. to XXXVIII.)

Synopsis.

Treatments of the melt which coarsened or refined the graphite eutectic structure in grey cast irons were found to have no corresponding effects on the iron-carbide eutectic in white cast irons. Differences in casting temperature, however, produced remarkable differences in the *primary* microstructure. In *hyper*eutectic white iron compositions, lower casting temperature greatly reduced the size of the primary carbide plates. In *hypo*-eutectic white iron compositions, it refined the dendritic structure of the primary austenite, so that it became replaced by a globular austenite structure. The microstructures are interpreted as showing that primary dendrites result from the joining up of globules, and that large primary plates result from the joining up of smaller plates. This may have a bearing on the " mosaic " structure in crystals. Lower casting temperature refined the dendritic structure of ordinary (γ-iron) compositions of grey cast iron in a similar manner. In the case of 14% silicon (δ-iron) grey iron compositions, however, it had no refining effect comparable with the above. This difference is attributed to the recrystallisation of γ-iron on solidification, due to the occurrence of the $\delta \rightarrow \gamma$ allotropic change and to the non-recrystallisation of δ-iron, both being assumed to be in the δ-iron allotropic condition in the liquid state. In the same way, it is suggested that pure carbon is in the diamond allotropic form in the liquid state, and solidifies without allotropic change when diamond is formed but with allotropic change when graphite is formed. In cast iron compositions, carbon is similarly assumed to be in the diamond form in the liquid state and to form a diamond-iron compound (iron carbide) when it solidifies without allotropic change, but to form graphite, as above, when it solidifies with allotropic change.

In an Appendix, it is suggested that elements in solid solution graphitise cast iron, while those forming compounds stabilise the carbide.

Part I.—Introduction.

(1) *Experiments on the Inoculation, &c., of the White-Iron Eutectic.*—In a previous investigation [2] it was found that the

[1] Received June 8, 1939.

[2] A. L. Norbury and E. Morgan, *Journal of the Iron and Steel Institute*, 1936, No. II., pp. 327-358.

treatment of molten cast iron with titanium plus carbon dioxide produced a remarkable effect in refining the graphite eutectic. Treatment with inoculants such as calcium silicide, &c., on the other hand, produced a coarsening effect. Tests were consequently carried out to see if the white iron-carbide eutectic was affected in a similar manner. No differences could, however, be produced by the above treatments or by a number of others that were tried. This is, in itself, an interesting point, since it shows that the non-metallic inclusions concerned have something in common with graphite, but not with iron carbide, since they "inoculate" the solidification of the former but not that of the latter. It also suggests that the graphite eutectic is not a decomposition product of the carbide eutectic.

(2) *Differences in the Microstructures of White Irons Produced by Differences in Casting Temperature.*—In the course of the above experiments, a number of different compositions of white cast iron were tested and it was noted that differences in casting temperature had a remarkable effect on the fracture of *hyper*eutectic white irons. If cast very hot the fracture was coarsely crystalline. If cast very cold it was finely crystalline and granular. Such differences are shown in Figs. 1 to 4. Microscopic examination showed corresponding differences in the size of the primary carbide plates. In *hypo*-eutectic white irons no such differences were visible from the *fracture*, but microscopic examination again showed extremely interesting differences in the primary microstructure, due to differences in casting temperature. Such differences were consequently studied in detail in the case of the above white iron compositions and also in grey iron compositions. They are illustrated by a number of micrographs, the description and discussion of which form the basis of Parts II., III. and IV.

The micrographs throw light on the manner in which primary carbide plates and primary dendrites are formed, and a theory of their formation is put forward. The micrographs also suggest that γ-iron does not solidify in exactly the same manner as δ-iron, and in Part V. a theory is put forward to account for this and for the solidification of diamond, graphite and carbide from molten iron-carbon alloys.

Previous investigations on the general subject of solidification and on the formation of microstructure are too numerous to summarise, but special mention may be made of those of Desch.[1] Concerning the effect of casting temperature on the microstructure of cast iron, the previous investigation which has been found to apply most directly is that of Hatfield,[2] who draws attention to differences in microstructure of white irons of approximately the same analysis, cast at different temperatures.

[1] C. H. Desch, *Journal of the Institute of Metals*, 1914, vol. 11, pp. 57–117; 1919, vol. 22, pp. 241–276.

[2] W. H. Hatfield, "Cast Iron in the Light of Recent Research," 1928, Chapter II., Figs. 29 and 30.

(3) *Compositions of Cast Irons the Microstructures of which are Illustrated; Casting Details, &c.*—In the course of the present investigation, a considerable number of different casts were made and examined microscopically, but micrographs of only certain typical compositions cast at different temperatures are shown (*see* Table I.). They were made from Swedish white iron (4·0% total carbon), steel, 30% ferro-silicon, 80% ferro-manganese and 70% ferro-chromium (9·5% total carbon). The 4·5% of chromium was alloyed in the white irons in order to prevent the formation of grey iron, which otherwise readily forms in high-carbon compositions, even if low in silicon. The 4·5% chromium content does not appreciably alter the white-iron microstructure, although in larger quantities, of about five times the carbon content, it alters the form of the primary carbide plates and also that of the white-iron eutectic, so that the latter consists of particles of carbide in an iron-rich matrix, instead of *vice versa*.[1]

TABLE I.—*Analyses of White and Grey Cast Irons the Microstructures of which are Illustrated.*

Description.	Analysis.						
	T.C. %	Si. %	Mn. %	S. %	P. %	Cr. %	Ti. %
Hypereutectic white iron . . .	4·56	0·32	0·70	0·03	0·02	4·50	...
γ hypo-eutectic white iron . . .	3·48	0·20	0·71	0·04	0·02	4·57	...
γ hypo-eutectic 2% silicon grey iron .	3·08	2·16	0·95	0·02	0·07	...	0·36
δ hypo-eutectic 14% silicon grey iron .	0·66	13·70	0·52	0·05	0·04	...	0·52

The charges (60 lb.) were melted in a salamander crucible, in a coke-fired, forced-draught pit furnace. From each charge were cast four test blocks such as are used in the manufacture of chill rolls, each 8 in. long by $4\frac{1}{2}$ in. high by $1\frac{1}{4}$ in. wide. The blocks were cast in open-topped, dry-sand moulds in which a 1-in. thick cast-iron chill formed the bottom of each mould. The four blocks were cast "hot," "medium hot," "cold" and "pasty" at about 1450°, 1375°, 1300° and 1250° C., respectively, and cooled in the mould to room temperature. The actual casting temperatures were not taken in the case of the blocks of which the microstructures are shown, since it delayed casting, but were taken in the case of other sets of blocks which gave corresponding differences in microstructure.

[1] *Cf.* C. R. Austin, *Journal of the Iron and Steel Institute*, 1923, No. II., p. 235.

PART II.—THE EFFECT OF CASTING TEMPERATURE AND CHILLING ON THE MICROSTRUCTURE OF HYPEREUTECTIC WHITE CAST IRON.

(4) *Equi-axed Primary Carbide Structures.*—The effect of casting temperature is most evident in the case of the hypereutectic composition, and this is consequently described first.

Figs. 1 to 4 show the vertical fractures of blocks cast hot, medium hot, cold and pasty. The chief features are, first, the change in the upper regions from a coarsely crystalline to a granular fracture, and, secondly, the decrease in length of the columnar crystals growing up from the chill. Considering the former first, it will be seen that in the upper, " equi-axed " (*i.e.*, non-columnar) regions, the fracture tends to follow the faces of the primary carbide plates. The diamond-like shape of the plates is sometimes evident and their thin, plate-like form is visible in the small shrinkage cavity in the top half of the block shown in Fig. 3.

The effect of lower casting temperature in decreasing the size of the equi-axed primary carbide plates is also shown in the micrographs in Figs. 5 to 8 at low magnification and in Figs. 9 to 12 at a higher magnification. Other details in Figs. 5 to 12, such as the streak markings in the carbide plates, and the eutectic structures are discussed later.

It will be noted that practically all the plates are seen in cross-section and not in plan in the micrographs. In the equi-axed regions shown, the microstructures were identical in horizontal and vertical sections (compare Figs. 7 and 15, and Figs. 8 and 16).

(5) *Columnar Primary Carbide Structures.*—Considering next the columnar primary structures, these are visible in Figs. 1 to 4, and are illustrated at low magnification in Figs. 13 to 16, which show them from the chill edge upwards for about $\frac{2}{3}$ in. They consist of long, narrow carbide plates, of which the lengths decrease from about $1\frac{1}{2}$ in. to $\frac{2}{3}$ in. to $\frac{1}{3}$ in. to nil with decreasing casting temperature in the four blocks shown. The cross-sections of the Fig. 13 columnar plates are shown at different distances from the chill edge in Figs. 17 to 19. Comparison of Figs. 17 and 18 with Fig. 13 indicates that the columnar plates have a long, thin, plank-like form, and that as they grow upwards they taper outwards, becoming thicker and wider and fewer in number. Fig. 19 shows that at their top ends they finally taper inwards and disappear in the equi-axed structure above. Fig. 20, of the edge of the columnar region $\frac{2}{3}$ in. from the chill, reveals that plates growing inwards from the sides, to an increasing extent with distance from the chill, give the columnar structure a conical shape, which is also evident in Figs. 1 to 3.

In Fig. 13 the columnar cone extends upwards beyond the top of the micrograph. In Fig. 14 it about reaches the top, in Fig. 15 about half-way up and in Fig. 16 there is no columnar cone. (It will be noted that the *vertical*-section *equi-axed* structures in the top half of Fig. 15 and in Fig. 16 are comparable with those in

the *horizontal* sections illustrated in Figs. 7 and 8, as indicated above.)

In addition to reducing the length of the columnar plates, lower casting temperature also reduces the number of plates growing upwards from the chill edge, and makes these plates more columnar or vertical. These features are evident in Figs. 13 to 15, and the reduction in the number of the plates is more definitely brought out in Table II., which is based on a count of the plates as shown in Figs. 13 to 15.

TABLE II.—*Number of Columnar Carbide Plates per Square Inch of Horizontal Cross-Section.*

	Cast Hot.	Cast Medium Hot.	Cast Cold.
At chill edge	200,000	140,000	80,000
$\frac{1}{8}$ in. from chill edge . .	90,000	40,000	8,000
$\frac{1}{4}$ in. from chill edge . .	14,000	1,500	...

In other words, lower casting temperature *coarsens* the columnar structure which grows upwards from the chill edge. This is noteworthy, since lower casting temperature also has the reverse effect, that is to say, it *refines* the equi-axed structure farther away from the chill, as is evident in Figs. 1 to 12. This suggests that lower casting temperature has two effects, as follows: (i) It *decreases* the initial rate of cooling by reducing the initial temperature difference between the molten metal and mould; (ii) it *increases* the subsequent rate by reducing the heat content of the molten metal. Of these, the first effect has the predominating influence in the early stages of cooling and determines the microstructure near the chill edge; the second effect predominates in the later stages and determines the equi-axed microstructure away from the chill. It is thought that these two effects explain why lower casting temperature increases the chill on a roll ((ii) predominating), but decreases it on the accompanying chill test-piece ((i) predominating).

(6) *Structure of White-Iron Eutectic.*—Figs. 9 to 12 show differences in the coarseness of the eutectic, due to differences in the rate of cooling produced by casting temperature, and local differences in its microstructure which might be interpreted as indicating the formation of fine and coarse white-iron eutectics under the same conditions of rate of cooling, as can occur in the case of the grey-iron eutectic. Figs. 21 and 22, however, of columnar eutectic in section and plan, show that the above local differences are only due to a sectioning effect; they reveal that the eutectic consists of colonies of parallel rods of austenite (black) in a matrix of carbide (white). The vertical section, Fig. 21, nearly always sections the rods laterally and rarely longitudinally, while the lengths of the rods lie in the horizontal section of the columnar structure. The carbide matrix

of the eutectic in Fig. 22 evidently takes its crystalline orientation from the nearest primary carbide plate and causes the austenite rods to adopt an orientation perpendicular to the plates. This is also evident in Figs. 9 to 12 and Figs. 5 to 7.

From the above, it is not evident whether the columnarisation of the eutectic is due to the orientating effect of the columnar carbide plates or to the temperature gradient. In the hypo-eutectic white irons described later, however, the same columnarisation of the eutectic occurs, owing to the temperature gradient, and the austenite primaries do not have any orientating effect (compare Figs. 44 and 43 with Figs. 21 and 22).

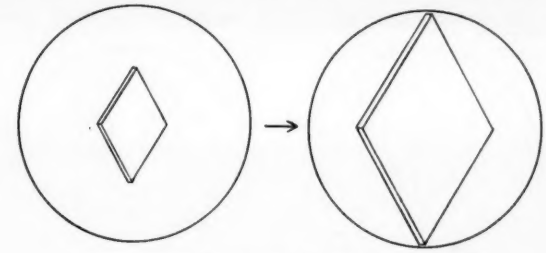
The austenite rods appear to be formed by the joining up of austenite globules, since their appearance often suggests this, and in rapidly cooled eutectic structures the proportion of rods to globules is very small (*e.g.*, in Fig. 12).

(7) *Formation of Large Primary Carbide Plates.*—A further interesting feature in the above micrographs is the presence of dark, streak-like markings in nearly all the carbide plates. These markings are visible in the low-power micrographs, but are more clearly seen in those at higher magnification, for example, in Figs. 9 and 10, which indicate that the markings are due to the coalescence of austenite from entrapped eutectic. The saw-like edges of some of the columnar carbide in Figs. 13 to 15 are another aspect of the same feature, as is shown in Fig. 23 illustrating the saw-edges and entrapped eutectic at a higher magnification. The diamond-like shape of the carbide crystals which have entrapped the eutectic in Fig. 23 is shown in another section (of a different area) in Fig. 24. These micrographs indicate, it is thought, that the large carbide plates in question are aggregates formed by smaller-sized plates joining up while the eutectic was still molten. On this view the large carbide plates are not formed in the conventional manner, as indicated in Fig. 57(*a*), by progressive growth, but are formed by growth plus aggregation, as indicated in Fig. 57(*b*). In Fig. 57(*b*), which is only diagrammatic, the carbide crystals are, for the sake of simplicity, drawn as plates. They would be more correctly drawn with diamond-shaped cross-sections, and as joining up accordingly, since they crystallise in the orthorhombic system.

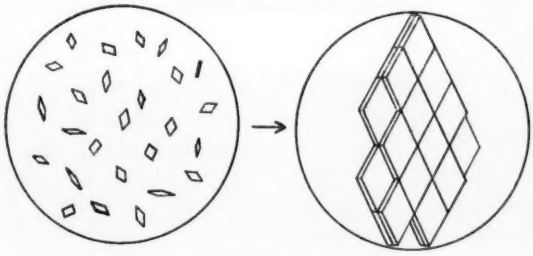
The present suggestion, consequently, is that two processes determine the formation of the large carbide crystals. One of these is crystal growth due to the deposition of further solid from the melt. The second is crystal aggregation due to the attraction and joining up of crystals in the still liquid eutectic. The second process also explains why the primary carbide plates in Fig. 9 are so much larger than those in Fig. 12, since the former could be imagined, from their included eutectic markings, to have been formed by the aggregation of plates of the size of the latter. This would be made possible by the slower solidification of the Fig. 9 block, in which the eutectic took three or four minutes to set, whereas in the Fig. 12 block it set

in a second or two after the metal had been poured into the mould.

Even the small carbide crystals in Fig. 12 are, however, in most cases, formed by the joining-up of still smaller crystals, as is revealed by the entrapped eutectic markings. Consequently, the size of the smallest crystals to aggregate is not clear, since the smaller the crystals, the less would be the tendency to entrap eutectic.



(*a*) Progressive Growth.



(*b*) Growth plus Aggregation.

FIG. 57.—Theories of Carbide Plate Formation.

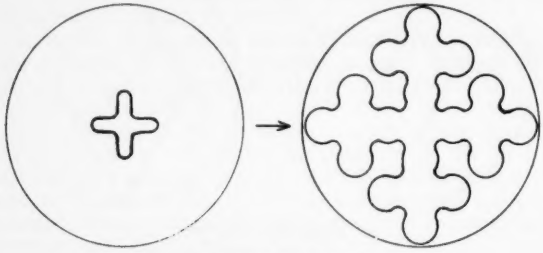
Crystals formed by aggregation in the above manner would be imperfect, the larger imperfections being visible in the above micrographs. The operation of the above aggregation process may, consequently, account for what is known as the "mosaic" or Zwicky structure in crystals, which is revealed by X-ray analysis. Etching pits may, similarly, be due to the same process.

PART III.—THE EFFECT OF CASTING TEMPERATURE AND CHILLING ON THE MICROSTRUCTURE OF γ HYPO-EUTECTIC WHITE CAST IRON.

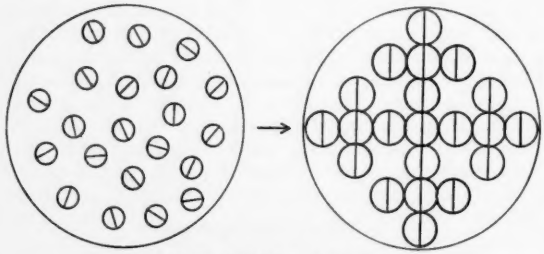
(8) *Equi-axed Primary γ Dendrite Structure.*—Test blocks similar to those shown in Figs. 1 to 4 were cast in a composition containing 3·5% instead of 4·6% of carbon (*cf.* Table I.), so that the primary

constituent consisted of γ, *i.e.*, austenite dendrites instead of carbide plates. The blocks revealed no marked difference in *fracture* due to casting temperature, since the fracture probably followed the eutectic rather than the primary dendrites. Microscopic examination, however, again indicated marked differences.

Figs. 25 to 28 and 29 to 32 show differences in the primary dendrite structure, in the equi-axed region, and are comparable with Figs. 5 to 8 and 9 to 12. The chief feature of these micrographs is that lower casting temperature makes the primary austenite



(*a*) Progressive Growth.



(*b*) Growth plus Aggregation.

FIG. 58.—Theories of γ-Iron Dendrite Formation.

structure increasingly less dendritic, but has little effect on the size of the austenite globules of which the dendrites appear to be composed.

(9) *Formation of Primary γ Dendrites.*—It is consequently suggested that dendrites are formed by the growth of austenite globules and the subsequent aggregation of the latter into dendrites. This is indicated in Fig. 58(*b*), and the conventional explanation of dendrite formation, by progressive growth, in Fig. 58(*a*). In the case of a pure metal, the final stages of solidification would be the same in Figs. 58(*a*) and (*b*) and would consist in the interdendritic liquid depositing solid on the dendrites in the usual manner.

Plate XXIII.

Hypereutectic White Iron.

Fig. 1.—Cast Hot.

Fig. 2.—Cast Medium Hot.

Fig. 3.—Cast Cold.

Fig. 4.—Cast Pasty.

Figs. 1 to 4.—Vertical Fractures of Hypereutectic White Iron Test Blocks, cast on chills. (T.C. 4·56%, Si 0·32%, Mn 0·70%, Cr 4·50%.) × 3.

[*Norbury.*

[*To face p.* 168 P.

HYPEREUTECTIC WHITE IRON.

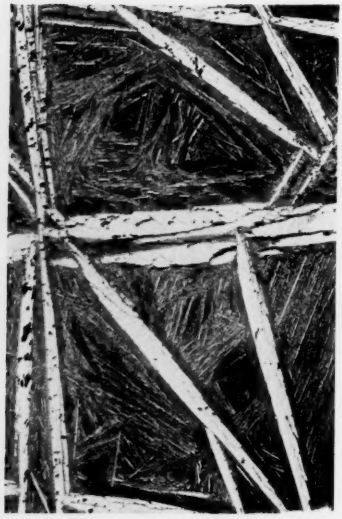


FIG. 5.—Cast Hot. Horizontal section $2\frac{1}{2}$ in. from chill edge (*cf.* Fig. 1). × 15.

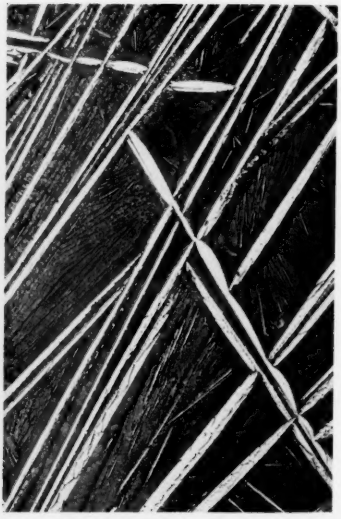


FIG. 6.—Cast Medium Hot. Horizontal section 2 in. from chill edge (*cf.* Fig. 2). × 15.

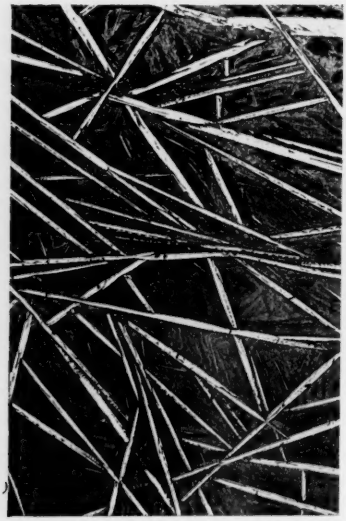


FIG. 7.—Cast Cold. Horizontal section $\frac{3}{4}$ in. from chill edge (*cf.* Fig. 3). × 15.

FIG. 8.—Cast Pasty. Horizontal section $\frac{3}{4}$ in. from chill edge (*cf.* Fig. 4). × 15.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Norbury.*

HYPEREUTECTIC WHITE IRON.

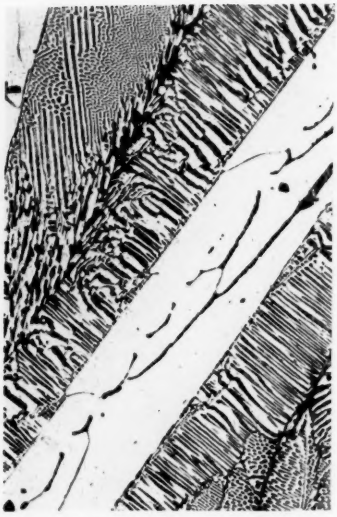


FIG. 9.—Cast Hot. Horizontal section 2½ in. from chill edge (*cf.* Fig. 5). × 100.

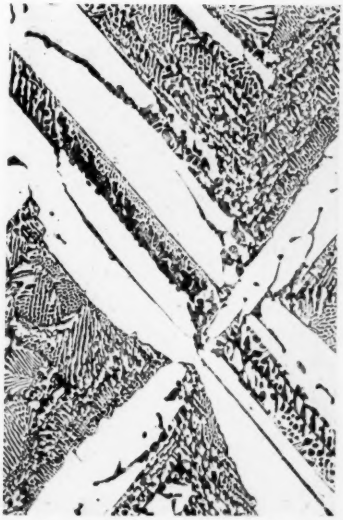


FIG. 10.—Cast Medium Hot. Horizontal section 2 in. from chill edge (*cf.* Fig. 6). × 100.

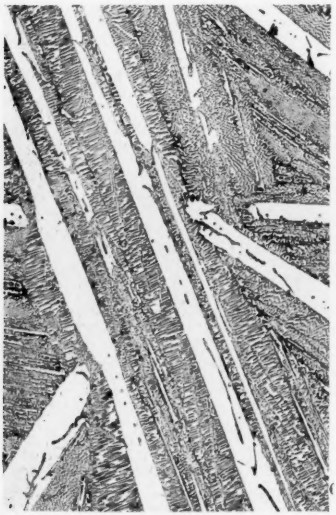


FIG. 11.—Cast Cold. Horizontal section ⅜ in. from chill edge (*cf.* Fig. 7). × 100.

FIG. 12.—Cast Pasty. Horizontal section ⅜ in. from chill edge (*cf.* Fig. 8). × 100.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Norbury.*

HYPEREUTECTIC WHITE IRON.

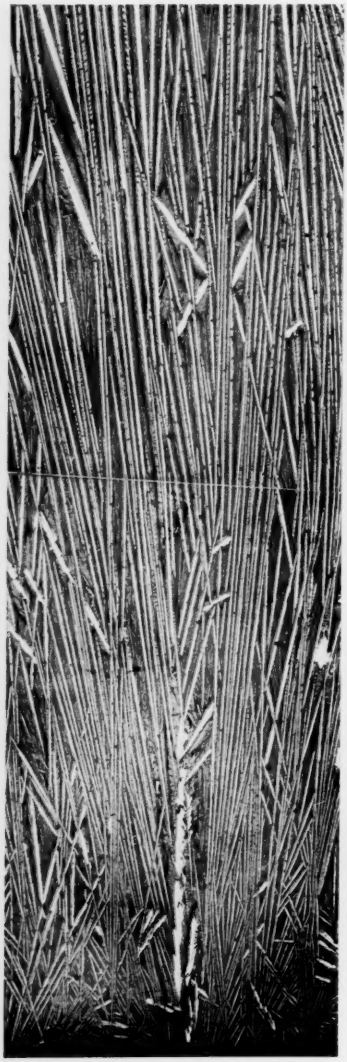


FIG. 13.—Cast Hot. Vertical section from chill edge upwards (*cf.* Fig. 1). × 15.

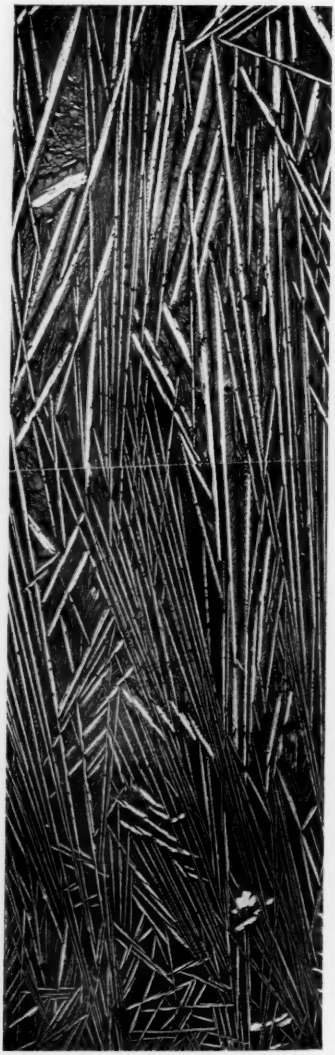


FIG. 14.—Cast Medium Hot. Vertical section from chill edge upwards (*cf.* Fig. 2). × 15.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Norbury.*

HYPEREUTECTIC WHITE IRON.

FIG. 15.—Cast Cold. Vertical section from chill edge upwards (*cf.* Fig. 3). × 15.

FIG. 16.—Cast Pasty. Vertical section from chill edge upwards (*cf.* Fig. 4). × 15.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Norbury.*

HYPEREUTECTIC WHITE IRON.

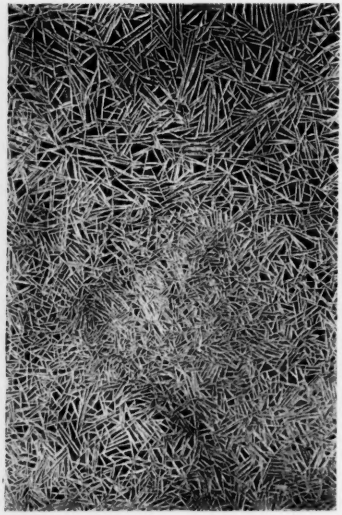


FIG. 17.—Cast Hot. Horizontal section at chill edge. × 15.

FIG. 18.—Cast Hot. Horizontal section $\frac{3}{8}$ in. from chill edge. × 15.

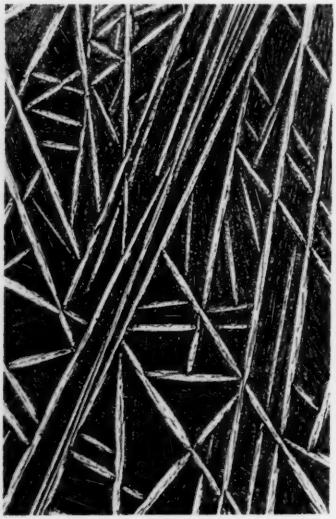


FIG. 19.—Cast Hot. Central horizontal section $1\frac{1}{4}$ in. from chill edge. × 15.

FIG. 20.—Cast Hot. Horizontal section, near side, $\frac{3}{8}$ in. from chill edge. × 15.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Norbury.*

HYPEREUTECTIC WHITE IRON.

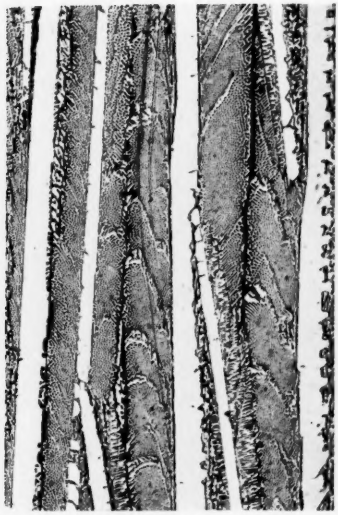


FIG. 21.—Cast Hot. Vertical section $\frac{3}{8}$ in. from chill edge. × 100.

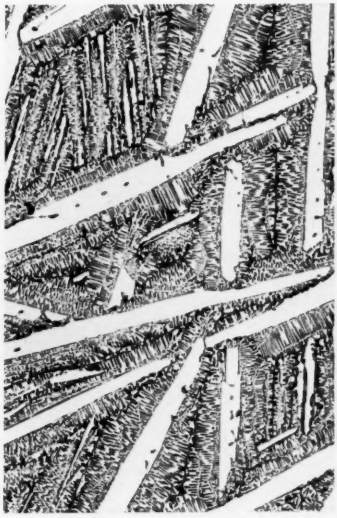


FIG. 22.—Same as Fig. 21, only horizontal section. × 100.

FIG. 23.—Cast Hot. Vertical section $\frac{1}{2}$ in. from chill edge. × 100.

FIG. 24.—Cast Hot. Horizontal section $1\frac{3}{4}$ in. from chill edge. × 100.

(Fig. 23 reduced to three-quarters linear, the others to two-thirds linear in reproduction.)

[*Norbury.*

γ HYPO-EUTECTIC WHITE IRON.

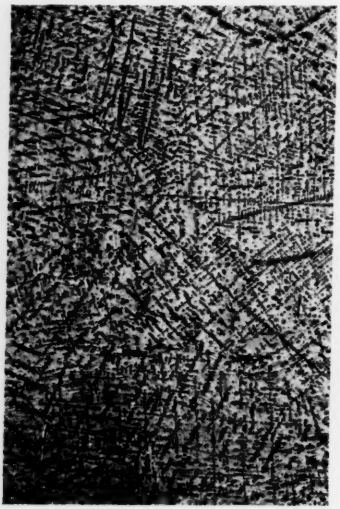


FIG. 25.—Cast Hot. Horizontal section, 2½ in. from chill edge. × 15.

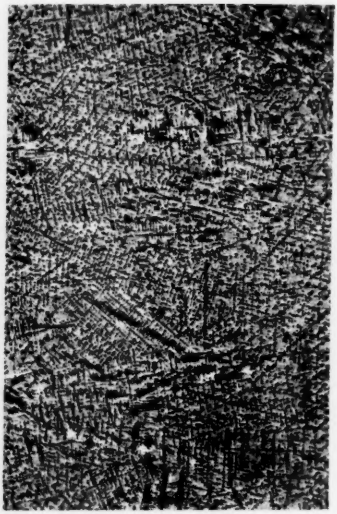


FIG. 26.—Cast Medium Hot. Horizontal section 2 in. from chill edge. × 15.

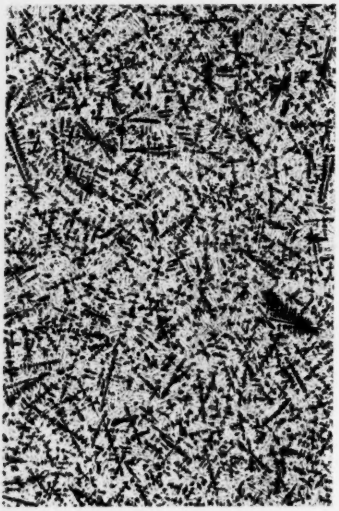


FIG. 27.—Cast Cold. Horizontal section ⅝ in. from chill edge. × 15.

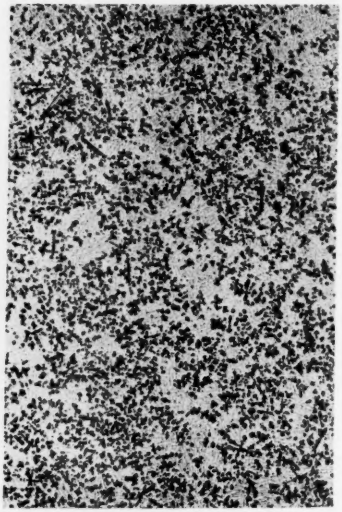


FIG. 28.—Cast Pasty. Horizontal section ⅝ in. from chill edge. × 15.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Norbury.*

γ HYPO-EUTECTIC WHITE IRON.

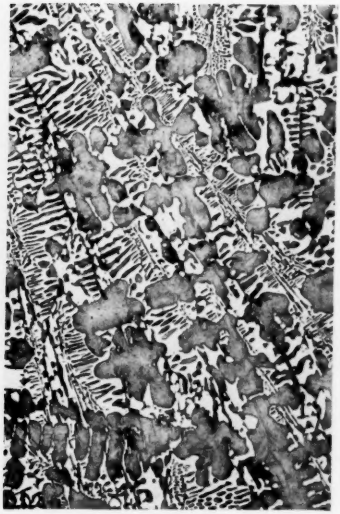


FIG. 29.—Cast Hot. Horizontal section 2½ in. from chill edge (*cf.* Fig. 25). × 100.

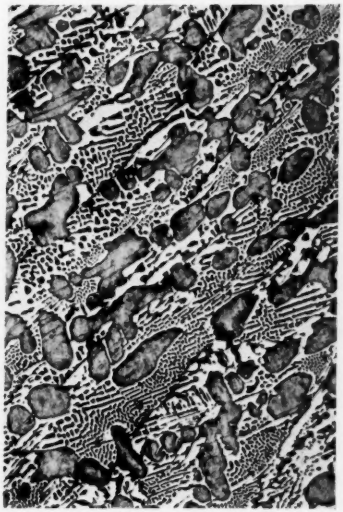


FIG. 30.—Cast Medium Hot. Horizontal section 2 in. from chill edge (*cf.* Fig. 26). × 100.

FIG. 31.—Cast Cold. Horizontal section ⅜ in. from chill edge (*cf.* Fig. 27). × 100.

FIG. 32.—Cast Pasty. Horizontal section ⅜ in. from chill edge (*cf.* Fig. 28). × 100.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Norbury.*

γ HYPO-EUTECTIC WHITE IRON.

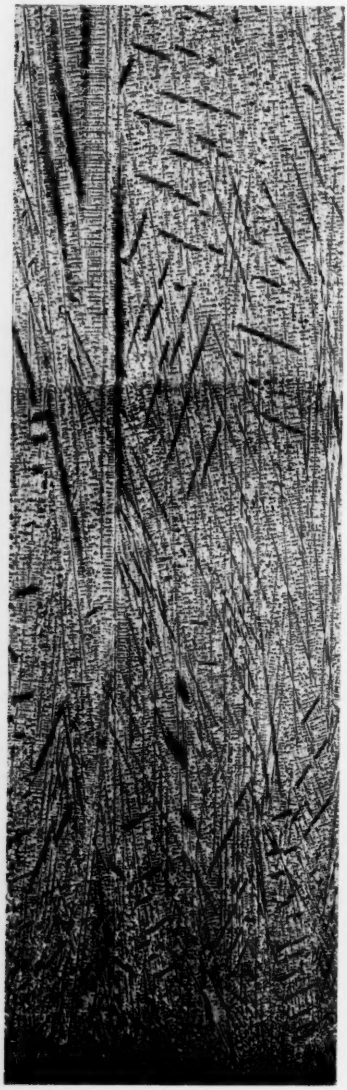


FIG. 33.—Cast Hot. Vertical section from chill edge upwards. × 15.

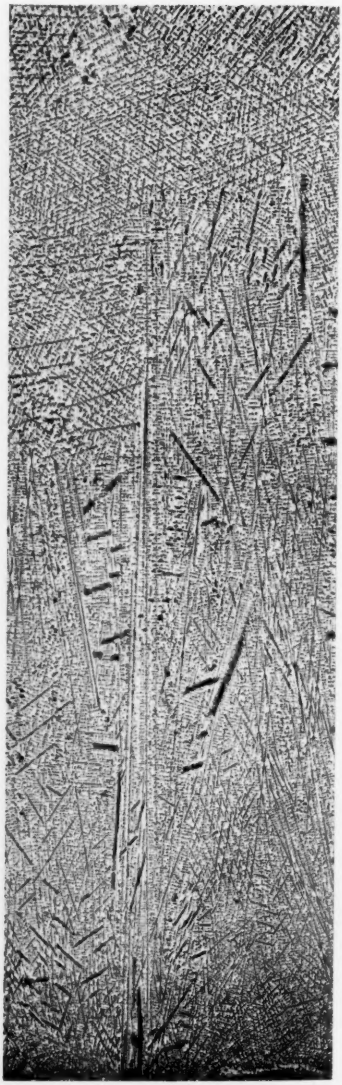


FIG. 34.—Cast Medium Hot. Vertical section from chill edge upwards. × 15.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Norbury.*

γ HYPO-EUTECTIC WHITE IRON.

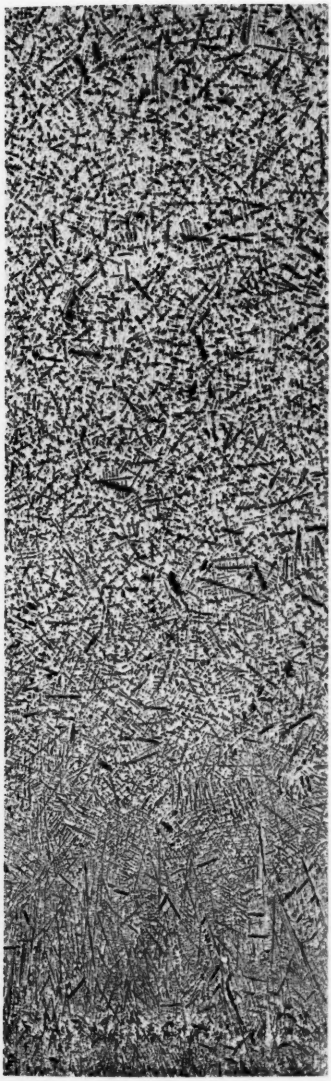


FIG. 35.—Cast Cold. Vertical section from chill edge upwards. × 15.

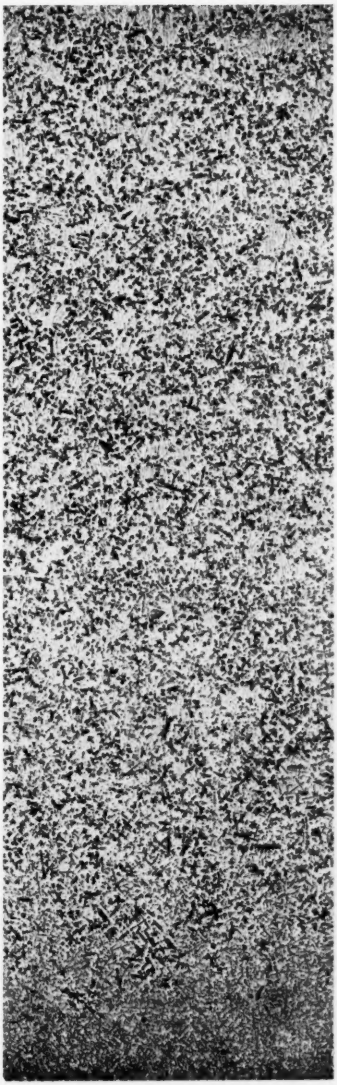


FIG. 36.—Cast Pasty. Vertical section from chill edge upwards. × 15.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Norbury.*

γ HYPO-EUTECTIC WHITE IRON.

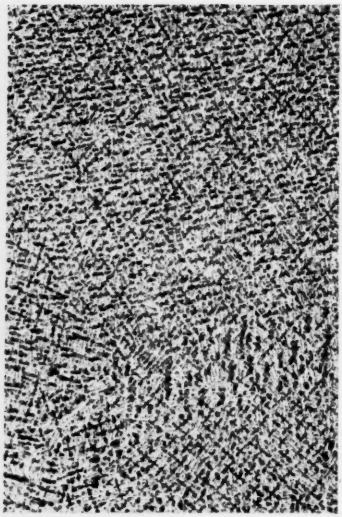


FIG. 37.—Cast Hot. Horizontal section at chill edge. × 100.

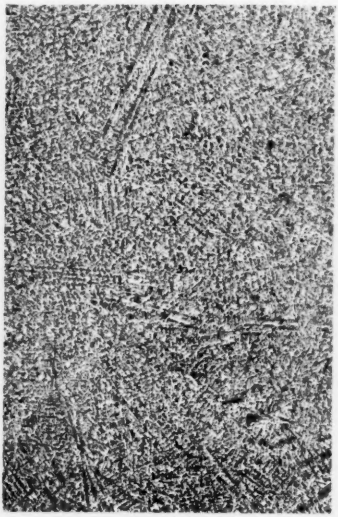


FIG. 38.—Cast Medium Hot. Horizontal section at chill edge. × 100.

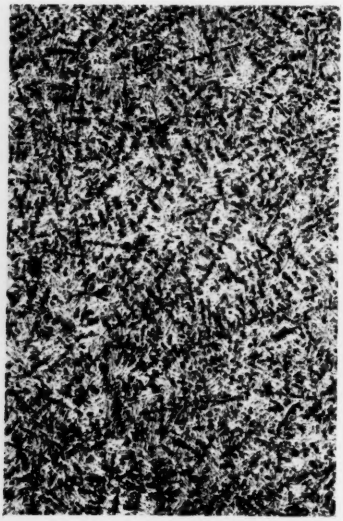


FIG. 39.—Cast Cold. Horizontal section at chill edge. × 100.

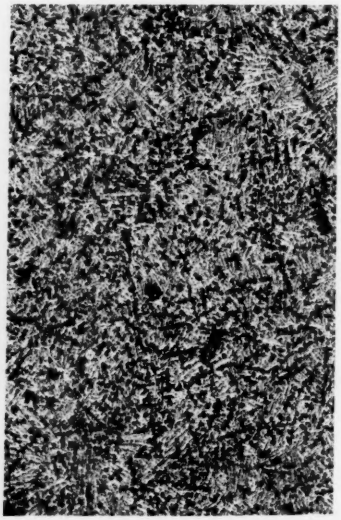


FIG. 40.—Cast Pasty. Horizontal section at chill edge. × 100.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Norbury.*

γ HYPO-EUTECTIC WHITE IRON.

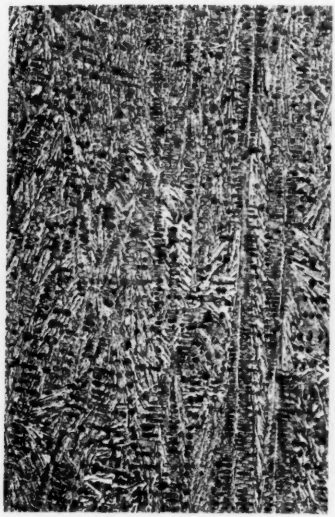


FIG. 41.—Cast Hot. Vertical section at chill edge (*cf.* Fig. 33). × 100.

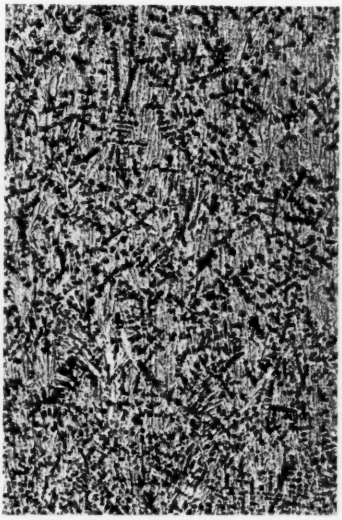


FIG. 42.—Cast Pasty. Vertical section at chill edge (*cf.* Fig. 36). × 100.

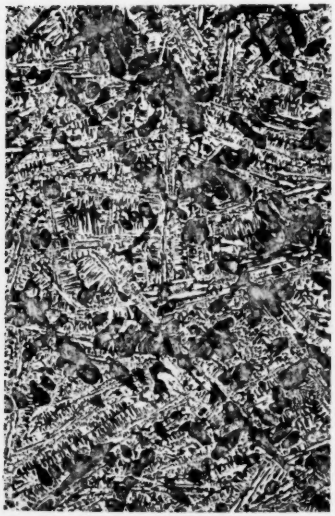


FIG. 43.—Cast Hot. Horizontal section $\frac{3}{8}$ in. from chill edge. × 100.

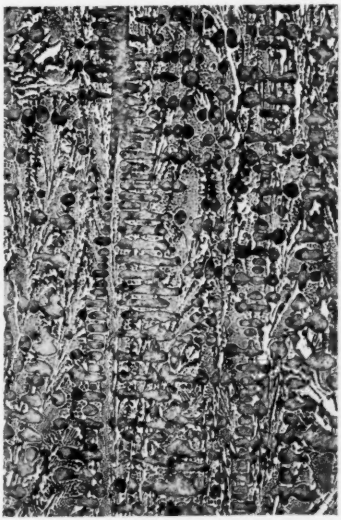


FIG. 44.—Same as Fig. 43, only vertical section (*cf.* Fig. 33). × 100.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Norbury.*

Plate XXXVI.

γ Hypo-eutectic 2% Silicon Grey Iron.

Fig. 45.—Cast Hot. Horizontal section 2 in. from chill edge (unetched). × 15.

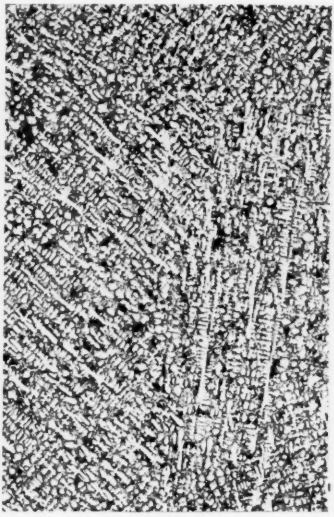


Fig. 46.—Cast Medium Hot. Horizontal section $1\frac{3}{4}$ in. from chill edge (unetched). × 15.

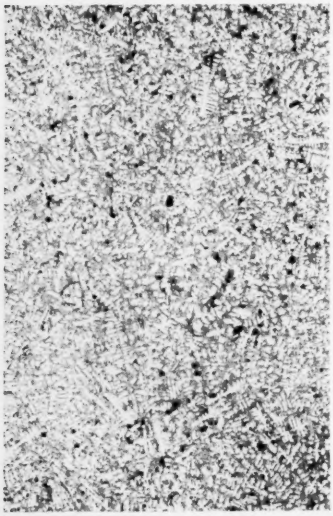


Fig. 47.—Cast Cold. Horizontal section $1\frac{1}{2}$ in. from chill edge (unetched). × 15.

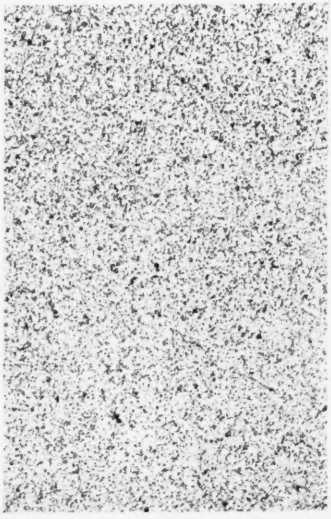


Fig. 48.—Cast Pasty. Horizontal section $1\frac{1}{2}$ in. from chill edge (unetched). × 15.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Norbury.*

δ HYPO-EUTECTIC 14% SILICON GREY IRON.

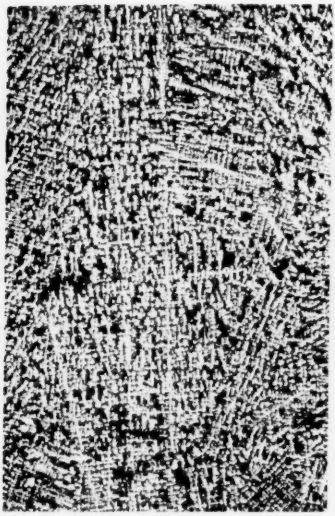


FIG. 49.—Cast Hot. Horizontal section 2 in. from chill edge. × 15.

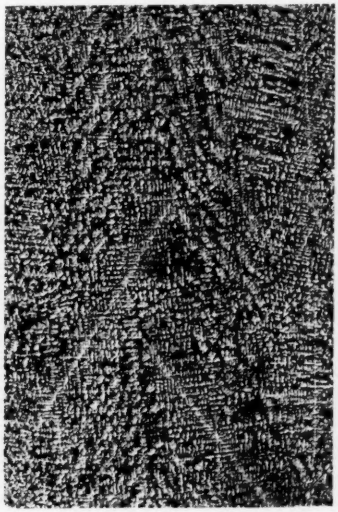


FIG. 50.—Cast Medium Hot. Horizontal section 1¾ in. from chill edge. × 15.

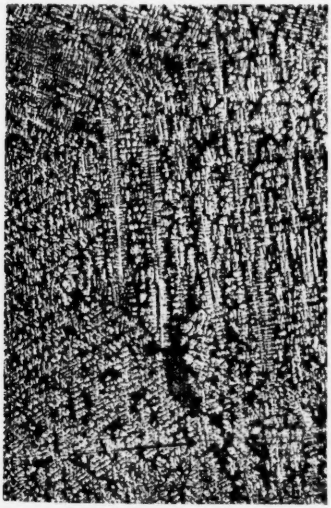


FIG. 51.—Cast Cold. Horizontal section 1½ in. from chill edge. × 15.

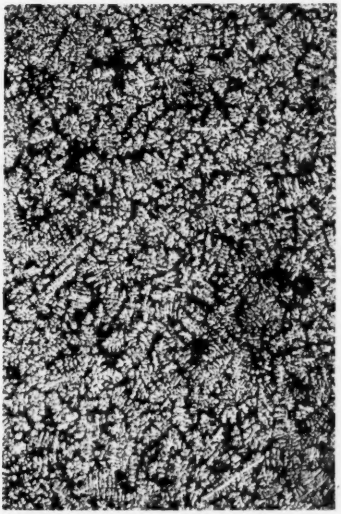


FIG. 52.—Cast Pasty. Horizontal section 1½ in. from chill edge. × 15.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Norbury.*

δ HYPO-EUTECTIC 14% SILICON GREY IRON.

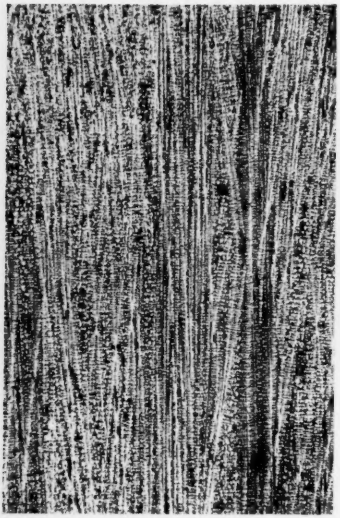


FIG. 53.—Cast Hot. Vertical section ⅜ in. from chill edge. × 15.

FIG. 54.—Same as Fig. 53, only horizontal section. × 15.

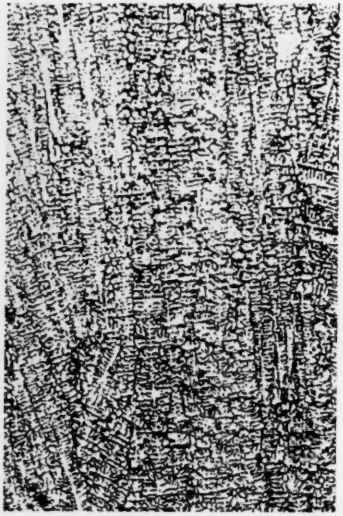


FIG. 55.—Cast Hot. Vertical section at chill edge. × 100.

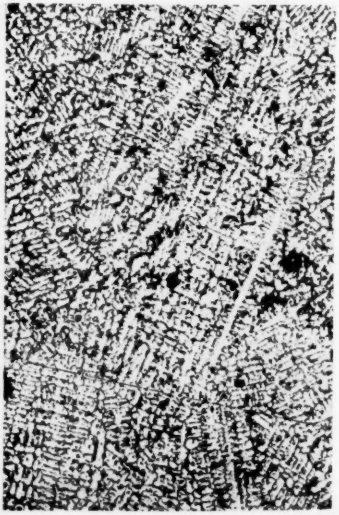


FIG. 56.—Cast Pasty. Vertical section at chill edge. × 100.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Norbury.*

[*To face p.* 169 P.

In Fig. 58(*b*) a line has been drawn in each globule to indicate that each has a single crystalline orientation and that they join up to form a dendrite having a single crystalline orientation. Similarly, the dendrites join up to form a crystal grain in which the dendrites have a single crystalline orientation. Consequently, the effect of lower casting temperature in Figs. 25 to 28 is comparable with a refining of the grain size of the primary austenite.

The explanation in Fig. 58(*b*) is the same in principle as that in Fig. 57(*b*), and the effect of low casting temperature in preventing the aggregation of the austenite globules into dendrites and crystal grains (Figs. 25 to 28) is the same as its effect of preventing the aggregation of small carbide plates into large carbide plates (Figs. 5 to 8).

(10) *Columnar Primary γ Dendrite Structure.*—The columnar primary γ, *i.e.*, austenite, structure and its reduction in length by lower casting temperature are shown in Figs. 33 to 36, which are comparable with Figs. 13 to 17. On the present explanation of dendritic growth, the columnar dendrites in Figs. 33 to 35 are formed by austenite globules forming in the temperature gradient and continuously joining on to and increasing the length rather than the side branches of the most vertical dendrites growing up from the chill edge. The equi-axed primary structures in the upper parts of Figs. 34 to 36 are similar to those shown in Figs. 26 to 28, since these structures were identical in vertical and horizontal sections of the test blocks.

The *horizontal* structures of Figs. 33 to 36 at the chill edge are shown in Figs. 37 to 40 (*N.B.*, at a higher magnification) and again demonstrate the effect of lower casting temperature in preventing the aggregation of the austenite globules. The structures show little effect of columnarisation, since they were those on which the columnar structure formed.

The vertical section of the columnar structure, based on the Fig. 37 horizontal structure, is shown in Fig. 41. Similarly, the vertical section of the equi-axed structure, based on the Fig. 40 horizontal structure, is illustrated in Fig. 42. The horizontal structure comparable with Fig. 37 only farther away from the chill appears in Fig. 43, which shows the rectilinear cross-sections of the columnar dendrites in this normal section.

Fig. 43 also illustrates the cross-section of the columnarised white-iron eutectic, the vertical section of the same area being shown in Fig. 44. The structure of the eutectic has already been discussed in connection with Figs. 21 and 22, with which Figs. 43 and 44 are comparable.

It will be noted that the equi-axed and columnar dendritic structures depicted in the above micrographs are, at the lower magnifications, almost identical with those obtained in steels, on the primary microstructure of which differences in casting temperature probably have very similar effects.

PART IV.—THE EFFECT OF CASTING TEMPERATURE AND CHILLING ON THE MICROSTRUCTURE OF γ AND δ HYPO-EUTECTIC GREY CAST IRONS.

(11) *γ Hypo-Eutectic Grey Cast Irons.*—The term γ hypo-eutectic grey cast iron is used to indicate that the primary dendrites consist of γ-iron or austenite, to distinguish them from the primary dendrites formed in 14% silicon cast-iron compositions, in which the dendrites consist of the allotropic δ form of iron. This formation of δ-iron dendrites is due to silicon increasing the area of the δ-iron region in the top left-hand corner of the iron-carbon diagram, so that with high silicon contents the δ area occupies the whole of the area to the left of the eutectic.

Chill blocks cast in the γ hypo-eutectic grey cast iron composition showed primary austenite dendrite structures in all ways comparable with those found in the γ hypo-eutectic white iron discussed in Part III. This was anticipated, since the primary dendrite formation is independent of whether the eutectic solidifies white or grey. Near the chill edge the eutectic solidified white, but the columnar dendrite structures were like those shown in Figs. 35 to 38. The equi-axed structures away from the chill are depicted in Figs. 45 to 48. These are comparable with the white-iron structures in Figs. 25 to 28, and it will be seen that the general effect of lower casting temperature, in preventing the aggregation of the austenite globules into dendrites, is the same in the grey iron as in the white iron already discussed.

In the iron illustrated in Figs. 45 to 48, the graphite eutectic structure was refined by treating the melt with titanium and carbon dioxide in order to make the dendritic structure stand out more clearly, since in coarse-graphite eutectic grey cast iron the eutectic austenite builds on to the primary dendrites and obscures them.

(12) *δ Hypo-Eutectic Grey Cast Iron.*—Chill blocks cast in the δ hypo-eutectic grey iron composition shown in Table I. had columnar and equi-axed microstructures similar to those of the above γ-iron, in so far as they consisted of dendrites plus fine graphite eutectic, but they showed an important difference in that their primary dendrite structures were not affected by casting temperature in the same way. That is to say, the δ-iron *equi-axed* structures in Figs. 49 to 52 correspond to the γ-iron structures in Figs. 45 to 48, but it will be seen that lower casting temperature has had little effect on the δ dendritic structures of Figs. 49 to 51, compared with its effect on the γ in Figs. 45 to 47. Even in Fig. 52, where the δ structure has been mechanically refined by casting in the pasty condition, it is very much more dendritic than the γ shown in Fig. 48 or the comparable *white iron* γ structure in Fig. 28.

The *columnar* dendrite structure in the δ-iron blocks cast "hot," "medium hot" and "cold" was also less reduced by lower casting temperature, being about $1\frac{3}{4}$ in., $1\frac{1}{2}$ in. and 1 in. long in the three

cases. In the cast "pasty" δ-iron block, however, it was again absent, since the block solidified in a second or two. Otherwise, the δ columnar structures were very similar to those in the γ hypo-eutectic white and grey irons, as shown in Figs. 53 and 54.

Another illustration of the relative non-effect of lower casting temperature on the δ-iron dendrites is given in Figs. 55 and 56 of the vertical chill-edge structures. The difference is shown by comparing Figs. 55 and 56 with the corresponding γ-iron structures in Figs. 41 and 42, in which the dendrite-refining effect is marked. This difference in the effect of lower casting temperature on the primary dendritic structure in γ- and δ-irons is suggested to be due to the fact that γ-iron undergoes an allotropic change, or recrystallises, at the moment of solidification, while δ-iron does not.

(13) *Formation of Primary δ Dendrites.*—On this view, the formation of δ iron dendrites is depicted diagrammatically in Fig. 59,

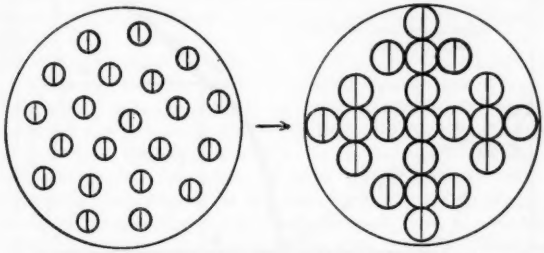


FIG. 59.—Theory of δ-Iron Dendrite Formation by Growth plus Aggregation (by progressive growth, as in Fig. 58(*a*)).

which differs from Fig. 58(*b*), showing the formation of γ-iron dendrites only in respect of the relative orientation of the globules before they aggregate to form dendrites. That is to say, in Fig. 58(*b*) the allotropic change to γ-iron is assumed to have destroyed the relative orientation of the γ-iron globules, but in Fig. 59 there is no such allotropic change, and the δ-iron globules, in a given liquid crystal grain, are assumed to have the same crystalline orientation on formation. Consequently, lower casting temperature will have a much greater effect in preventing the aggregation of the non-orientated γ-iron globules in Fig. 58(*b*) into dendrites, than in preventing the aggregation of the oriented δ-iron globules in Fig. 59 into dendrites, which is the indication of the micrographs. A similar difference in the effect of casting temperature has been found between the α and β phases in both the copper-zinc and the copper-aluminium systems, and is attributed to a similar cause.

PART V.—THEORY OF THE SOLIDIFICATION OF IRON-CARBON ALLOYS.

(14) *Solidification of δ- and γ-Iron.* The above finding that lower casting temperature has a different effect on the dendritic structure of δ-iron as compared with γ-iron was actually anticipated from theoretical grounds, and led to the above experimental comparison being made.

The supposition was based on the following arguments relative to the iron-carbon diagram, which is shown diagrammatically in Fig. 60: (1) Liquid, carbon-free iron, as it approaches its freezing

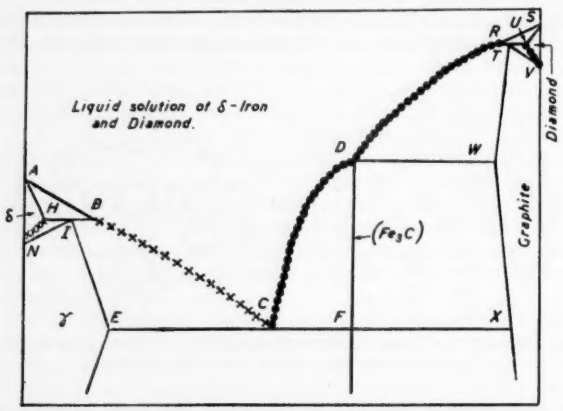


FIG. 60.—Theory of Allotropic Changes in Iron-Carbon Alloys (diagrammatic and not to scale).

point, has some characteristic crystal lattice such as body-centred cubic or face-centred cubic, &c., as has been found in the case of low-melting-point metals in the liquid state. (2) If this liquid lattice does not alter in type above the line *ABC* as the carbon content increases, either δ- or γ-iron, or both, must solidify from the melt, with an accompanying lattice change, since solid δ is body-centred cubic and solid γ is face-centred cubic. (3) On this basis there are three possibilities: (*a*) The liquid lattice is body-centred cubic like that of δ-iron. Consequently compositions in the γ range change from body-centred cubic to face-centred cubic on solidification along *BC*. Compositions in the δ range, however, solidify along *AB* without lattice change, but undergo the same $\delta \rightarrow \gamma$ lattice change in the solid state, along *HN*; (*b*) alternatively, the liquid lattice is face-centred cubic like that of γ-iron. In this

case γ compositions would solidify without lattice change, while δ would change to body-centred cubic on solidification and then back to the same face-centred cubic lattice in the solid state along *HN*. This is more complicated and less probable; (*c*) alternatively, the liquid lattice is different from that of either δ or γ. In this case, more complicated and less probable lattice changes have to be assumed. Consequently, of the above three possibilities, (*a*) is the simplest and most probable. It also agrees with the different effect of casting temperature on the dendrite-structure formation in δ and γ cast irons, as discussed above in Part IV.

Put in another way, the argument is as follows: What happens to the $\delta \rightarrow \gamma$ allotropic change line *NH* in Fig. 60 in the case of compositions to the right of the point *B*? Does the line continue into the liquid region above *ABC*,[1] or does it continue along *BC*? The present suggestion is that it continues along *BC*, as indicated in Fig. 60, and that the liquid above *ABC* has the same allotropic form and crystal lattice as δ-iron, and solidifies in accordance with 3(*a*) above.

(15) *Solidification of Diamond and Graphite.*—The above explanation of the way in which the δ and γ allotropic forms of iron solidify may be applied in an analogous manner to explain the way in which the diamond and graphite allotropic forms of carbon solidify. This is also shown in Fig. 60, in which, in the top right-hand corner, a hypothetical region has been drawn which corresponds in construction with the δ region on the left of Fig. 60. The diamond form of carbon, corresponding with the δ form of iron, is assumed to be the form existing in the liquid state, and graphite, corresponding with γ, to be the form stable at lower temperatures. It is generally supposed that diamonds are formed by the rapid cooling of liquid carbon, and the diagram is in accordance with this, since rapid cooling would tend to prevent the diamond $\rightarrow$ graphite allotropic change along *UV*, just as rapid cooling prevents the allotropic change when steels are quenched. Another analogy is that of pouring liquid sulphur into water, in which case the metastable, plastic allotropic form of sulphur is retained by quenching. Fig. 60 is also in accordance with the fact that solid diamond is metastable and decomposes into graphite on tempering.

(16) *Solidification of Iron Carbide and Graphite.*—In Fig. 60, the diamond $\rightarrow$ graphite allotropic change *VU* is shown as continuing along the liquidus *RDC*, just as the $\delta \rightarrow \gamma$ change *NH* is shown as continuing along *BC*. The deposition of solid graphite along *RC* is consequently analogous, in so far as the diamond $\rightarrow$ graphite allotropic change is assumed to accompany the solidification of carbon, to the deposition of solid γ-iron along *BC*.

In order to explain the solidification of carbide, it is assumed that

[1] In the iron-copper diagram, two immiscible liquids are formed in the région above the point corresponding to *B* in Fig. 60. This may be due to the *NH* line, in this case, continuing from *B* into the liquid region.

when carbide is deposited along *DC*, the solidification of carbon is not accompanied by the diamond-to-graphite allotropic change; also that, owing to the composition of the melt, a metastable diamond-iron compound is formed instead of pure diamond. The composition of the metastable compound (Fe_3C) is indicated diagrammatically by *DF*.

This affinity of iron for the diamond form of carbon has a stabilising effect on the latter, and this effect increases as the ratio of iron to carbon increases. Consequently, in the γ solid solution deposited along *BC*, in which the carbon is also assumed to be in the diamond form, it is stable owing to the affinity of the surrounding iron atoms, and not metastable. Iron carbide not in solid solution is, however, metastable and, like diamond, decomposes into graphite on tempering.

The author thanks the Council of the British Cast Iron Research Association for permission to publish the present results. Credit for the micrographs is due to Mr. H. Morrogh and other members of the staff.

Appendix I.—*Effects of Alloying Elements on the Stability of Iron Carbide.*

In connection with the stability of iron carbide, discussed above, it is suggested that those alloying elements which have a graphitising action are those which form solid solutions in cast iron, and that those which have a carbide-stabilising action are those which form compounds.

For example, the chief graphitising elements aluminium, silicon, cobalt, nickel and copper all form solid solutions. On the other hand, the elements which have been found to stabilise the carbide, boron, magnesium, sulphur, vanadium, chromium, manganese, arsenic, selenium, molybdenum, tin, antimony, tellurium, tantalum and tungsten, have all been found to form compounds such as carbides, sulphides, iron compounds, &c., visible as separate phases in the microstructure.

The case of aluminium is particularly significant, since first additions of it form a solid solution and have a powerful graphitising action, while additions above a certain figure form a compound which has a powerful carbide-stabilising action. Similarly, additions of phosphorus reduce the combined-carbon content of grey cast iron, but the carbide nearest to the phosphide compound visible in the microstructure is always the last to decompose. It seems probable that this phosphide has a carbide-stabilising action, while phosphorus in solid solution has a graphitising action.

Other elements such as chromium, manganese and molybdenum, when alloyed, partly form carbides and partly enter into solid solution in cast iron, their distribution in this manner depending on

the amounts present and on the amount of carbon present. In the case of chromium, for example, it has been found [1] that in steels, all of it forms carbide and none goes into solid solution until it exceeds 4·3 times the amount of carbon present.

The indication consequently appears to be that compounds in cast iron favour the formation of the iron-carbide compound. This may be connected with the similar nature of the attractive forces between the constituent atoms in the compounds and in the iron-carbide compound.

Elements in solid solution, however, have the opposite effect of making iron carbide unstable or of graphitising it. This may be connected with the distortion of the iron lattice produced by elements in solid solution, since elements like aluminium and silicon, the atoms of which differ considerably in size from those of iron, have a much more powerful graphitising action than elements like cobalt, nickel and copper, the atoms of which are not very different in size from those of iron. This distortion of the iron lattice, by tending to communicate itself to the iron-carbide lattice on account of the attractive forces between the iron atoms in each, may make the latter unstable.

[1] C. A. Edwards and A. L. Norbury, *Journal of the Iron and Steel Institute*, 1920, No. II., p. 481.

CORRESPONDENCE.

Dr. ICHIRO IITAKA (Institute of Physical and Chemical Research, Komagome, Hongo, Tokyo, Japan) wrote that he was much interested in the author's paper. The results were in many respects in accordance with his own observations and opinion. Particularly, the explanation made in the first paragraph on p. 174 was in complete

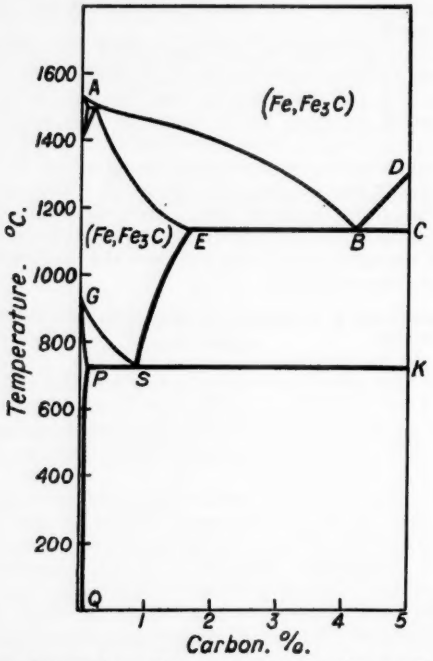


FIG. A.—New Iron-Carbon Diagram. Fe–C, stable equilibrium at low temperatures; Fe–Fe_3C, stable equilibrium at high temperatures. (Iitaka, *Scientific Papers of the Institute of Physical and Chemical Research, Tokyo*, 1937, vol. 33, p. 274, Fig. 1.)

agreement with that which he had given in conjunction with his diagram [1] for the Fe–C system (*see* Fig. A).

The fact that the fracture showed no marked difference due to the variation in the casting temperature (second line, p. 168 of the author's paper) might be explained by the fact that the fineness of the dendrites was quite independent of the casting temperature

[1] I. Iitaka, *Scientific Papers of the Institute of Physical and Chemical Research, Tokyo*, 1937, vol. 33, pp. 273–287. *Nature*, 1937, vol. 140, p. 462.

(*see* Figs. 25 to 28 of the author's paper). The path of fracture always followed along the dendrite or globule boundaries [1] (not along the eutectic) and the fineness of the fracture was always the same as that of the dendrites.

Dr. Iitaka, who was also interested in the same field of study, desired to congratulate the author on his valuable contribution to the study of the iron-carbon alloys, and wished him further success in his brilliant work.

Dr. L. NORTHCOTT (Research Department, Woolwich) wrote that the chief conclusion to be drawn from a study of this paper was that the author's interpretation of the experimental work was open to considerable criticism. A few of the more important items were discussed below in the order in which they appeared in the paper.

(1) The theory of mosaic structure and carbide plate formation appeared to be based upon the presence in the carbide plates of entrapped streaky deposits of austenite. Since the entrapping of a second phase as impurity was quite a common feature in the growth of crystals when solidified or crystallised from an impure solution, it was not quite clear in what way this example was unique. The only feature calling for comment about the carbide deposits was that the impurities were streaky instead of globular, and this was to be expected from the strongly directional manner of growth of the iron carbide; the orientated inclusion of impurities in crystals was a well-known feature, which had been much discussed, for example, by H. E. Buckley.

(2) It was a pity that in several of the Plates the microstructures shown were not from the same position in the different blocks; as a result of this, evidence was lacking for certain of the author's statements—in fact, in some instances the evidence shown was in contradiction to the statements made. An example would be found in Plate XXXI. and p. 168 of the paper, where the author stated that the lower casting temperature had little effect on the size of the austenite globules of which the dendrites appeared to be composed.

No justification was seen for the author's theory (pp. 168–169) of the effect of lower casting temperature in reducing the size of the austenite dendrites, nor for his theory of the formation of primary γ dendrites, based upon globular austenite forming in the liquid and continuously joining on to the already-formed dendrites. The microscopical study of the crystallisation of those non-metallic salts or elements which could be observed during their growth in a dendritic form from supersaturated solutions revealed that the method of growth was different from that suggested by the author for austenite, and it was not considered that the experimental results described in the paper suggested that there was a different mechanism of growth in the case of austenite. The influence of

[1] I. Iitaka and I. Yamagishi, *Scientific Papers of the Institute of Physical and Chemical Research, Tokyo*, 1938, vol. 34, pp. 1025–1033.

surface tension in rounding the dendritic branches, especially those of low order, tended to give a false impression of the three-dimensional structure of the dendrites when examined in a plane section.

(3) The claim (pp. 170–171) that in δ hypo-eutectic grey cast iron the primary δ dendritic structures were relatively not affected by the casting temperature was not supported either by the structures or by the measurements given. For example, the lengths of the columnar dendrites in the δ hypo-eutectic grey cast iron blocks were given as $1\frac{3}{4}$ in., $1\frac{1}{2}$ in., 1 in. and nil for the hot, medium-hot, cold and pasty temperatures, the only other measurements reported being $1\frac{1}{2}$ in., $\frac{3}{8}$ in., $\frac{1}{4}$ in. and nil for a hyper-eutectic white cast iron at similarly described temperatures. The most that could be said was that the casting temperature effect was less pronounced with the δ than the γ irons, and in view of the difference in composition and in freezing range of the two alloys it would be surprising if they were identical; the difference in columnar growth might be adequately explained by the lower freezing range of the high-silicon alloy, as shown, for example, by Honda and Murakami. There appeared to be no justification for the theory of δ iron dendrite formation described in the paper.

(4) The theory in Part V. of the paper was based upon the assumptions that a lattice formed in the liquid at some temperature above the freezing point and that this lattice did not alter in type, even over a wide range of chemical composition or even when the first-formed solid was of different lattice type. These assumptions, which were quite unsupported by any experimental or theoretical evidence, rendered the author's theory purely speculative in character.

AUTHOR'S REPLY.

(Fig. B = Plate XXXVIIIA.)

The AUTHOR, in reply, wrote that it was very satisfactory that Dr. Iitaka, after working along somewhat different lines, had arrived at similar conclusions with regard to the iron-carbon diagram. Dr. Iitaka's paper would have to be consulted for the arguments that he put forward, but his main conclusion was that molecules of iron carbide existed in the liquid state and decomposed, on slow cooling, into graphite and iron along the lines *BD* and *EBC* of his Fig. A. If, however, the cooling was sufficiently rapid, metastable iron carbide solidified.

Dr. Iitaka's observations on the path of the fracture were, the author thought, also in accordance with those in the paper. He was much obliged to Dr. Iitaka for his kind appreciation of the work.

In reply to Dr. Northcott, it was not clear in the first item of his discussion whether he did, or did not, accept the idea that the large

FIG. B.—Phosphoric White Cast Iron. The austenite globules, of the binary austenite-cementite eutectic, have aggregated to form dendrites, and the carbide to form plates. The binary eutectic has lost its characteristic "eutectic" structure. The ground-mass is ternary phosphide-carbide-austenite eutectic. × 200.

(*See* Author's reply.)

[*Correspondence on Norbury.*
[*To face p.* 178 P.

UNIV. OF MICH.

carbide plates were formed as in Fig. 57(*b*). This was the point at issue. That certain crystals did aggregate in this manner was well known. For example, if a substance such as phenyl para-toluene sulphonate was crystallised from a warm ethyl-alcohol solution, a shower of small crystals was first deposited. These sank in the liquid and aggregated into large imperfect plates. This was the process indicated in Fig. 57(*b*). The microscopic evidence in the paper was consistent with the idea that the large carbide plates had been formed in this manner, whereas he (the author) thought it had previously been assumed that they were formed by progressive growth, as shown in Fig. 57(*a*).

With regard to the second item, the globule size was well known to be affected by the distance from the chill, and this had to be taken into account in comparing Figs. 29 to 32 in Plate XXXI. Allowing for this factor, it was thought to be quite clear from these, and from the other micrographs, that the casting temperature had little effect on the globule size. The main argument in the paper on this point was that the globule size, and consequently the number of globules, was similar in the " cast hot " and " cast pasty " hypo-eutectic structures. Therefore the globules in each case were formed by the same process. The difference between the above structures consequently lay in the fact that the globules were joined up into dendrites in the former, but not in the latter. The micrographs did not suggest that the dendrites in the former had broken up into globules in the latter, but they were consistent with the idea that the globules in the latter had joined up into dendrites in the former. Moreover, such aggregation would be similar to that of the carbide.

That austenite globules could join up to form dendrites in the above manner could also be inferred from Fig. B of a phosphoric white iron. (A similar structure was shown in " Metallurgy of Cast Iron ", by J. E. Hurst, Fig. 58, p. 124.) In Fig. B the ground-mass was the ternary phosphide-carbide-austenite eutectic which solidified at about 950° C. The other constituents in Fig. B were white carbide plates and half-tone austenite dendrites. The latter had resulted from the aggregation of the austenite globules in the binary carbide-austenite eutectic, which had completely lost its characteristic " eutectic " appearance. This had been made possible by the solid austenite globules being able to aggregate in the still liquid ternary eutectic. The carbide in the eutectic had aggregated into large plates in a similar manner.

The operation of the same phenomenon presumably accounted for the absence of characteristic " eutectic " structures in complex igneous rocks, &c.

Dr. Northcott's argument relating to the dendritic crystallisation of salts was one which had actually been borne in mind, and the following explanation was suggested : When a salt such as potassium iodide was dissolved in an aqueous ethyl-alcohol solution and

allowed to crystallise on a glass slip, the process was somewhat as follows. Small isolated cubes were formed and these first grew by becoming progressively larger while maintaining their cubic form. After a time, however, growth by this process became very slow, and crystal growth by a different process took its place. In the second process, dendritic formations appeared to shoot out in a "jerky" manner from the cube corners. The first process was then repeated by cube corners growing outwards from along the dendrite arms. After a time the second process was repeated, and so on. In the first process salt diffused to the crystal and no supercooling occurred. The second process was, however, characterised by supercooling, and supercooling resulted in the formation of a labile shower of small crystals. The suggestion, consequently, was that in the second process the dendrites resulted from the aggregation of a labile shower of crystals. This was the process of dendrite formation which was indicated diagrammatically in Fig. 58 (*b*). Differences in the relative speeds, &c., of the above two processes in different substances and under different conditions would result in intermediate conditions of growth between the extremes described.

With regard to the third item in Dr. Northcott's discussion, the different reactions of γ and δ hypo-eutectic compositions to casting temperature were not shown so much by differences in columnar crystal length as by differences in equi-axed structure. Such differences were shown by comparing Plates XXX., XXXVI., XXXVII., &c.

With regard to the fourth item, the argument in the paper had reference not only to the liquid lattice but also to the allotropic condition of the atoms in the liquid state. It was not intended to imply that the δ-iron lattice was maintained throughout all liquid iron-carbon compositions. This was evidently impossible. The suggestion in Fig. 60 was that liquid iron atoms were in the δ-iron allotropic form in all such compositions and that the liquid carbon atoms were in the diamond allotropic form in all such compositions. That was to say that in liquid carbon, for example, the outer electrons or energy distributions of the atoms, which determined the solid lattice, were similar to those in diamond and not to those in graphite. In diamond, all four valency electrons were in a similar energy condition, whereas in graphite three of them were in a similar condition, while the fourth was in a different condition.

TENSIONAL EFFECTS OF TORSIONAL OVERSTRAIN IN MILD STEEL.[1]

By Professor H. W. SWIFT, M.A., D.Sc.(Eng.), M.I.Mech.E.
(The University of Sheffield).

(Figs. 13 to 22 = Plates XXXIX. and XL.)

Summary.

This paper is concerned with the effects of initial torsional strain on the plastic stress-strain relationship and conditions of rupture of mild steel in tension.

The conditions of rupture are discussed in the light of accepted facts; it is suggested that rupture in mild steel may occur either by tensile or by shear stress and that overstrain tends to weaken the metal in shear in a directional manner.

Results are given of tensile tests on mild-steel bars previously subjected to various degrees of torsional overstrain. These results support the conclusions that the inception of plastic flow is affected by the internal stress system, that the subsequent plastic stress-strain relationship is affected, but only in its initial stages, by the previous strain history of the bar, and that the circumstances of ultimate rupture cannot in general be predicted in terms of any single one of the following conditions: Tensile stress, shear stress, strain energy, hardness.

The tests also show that the relationship between principal shear stress and shear strain under plastic conditions is not independent of the system of applied stress, nor is the resistance to further plastic strain controlled by either hardness or strain energy.

Available Range of Plastic Flow.

The usefulness of a material for manipulative processes such as deep-drawing, in which severe plastic deformation is involved, depends primarily on the range of plastic flow to which it can safely be subjected. This depends in turn on:

(1) The impressed conditions necessary for the inception of plastic strain in the material,

(2) The stress-strain characteristics for the material in the plastic range, and

(3) The cohesive properties of the material which resist rupture.

The so-called conditions of elastic breakdown have been the subject of much study and controversy. Several theories still have their champions, but modern opinion seems generally to regard maximum stress as the criterion of breakdown for brittle materials

[1] Received May 31, 1939.

and shear-strain energy (or shear stress on the octahedral planes, to which this is implicitly related) for ductile materials. That there should be any conflict between theories for brittle and theories for ductile materials indicates a confusion of ideas as between conditions necessary to produce plastic strain and conditions necessary to produce rupture. In brittle materials the conditions of rupture commonly intervene before those of plastic flow; in ductile materials plastic flow occurs long before the conditions of rupture are reached. Since plastic strain is of primary interest in the present paper, shear-strain energy will be regarded provisionally as a working criterion of its inception.

The relationships between stress and strain in the plastic region are, of course, closely bound up with the property of strain-hardening. They have been the subject of experimental study within a limited field [1] and of certain speculative theories concerned primarily with strain-hardening. Under compound stress systems little is known of the stress-strain relationships, but the load-extension diagram in simple tension and the torque-twist diagram in simple torsion are familiar characteristics the true significance of which is seldom studied. There is a common belief that "flow curves" connecting principal shear stress and strain are similar in form under tensile, compressive and shear conditions of stress, based on a certain amount of experimental evidence over a limited range.[2]

Conditions of Rupture.

The extent to which plastic flow can continue to take place is limited by the conditions of ultimate rupture of the material. As already pointed out, these conditions are fundamentally distinct from those of elastic breakdown. They have been less studied than the latter, no doubt because elastic failure is a more imminent and scarcely less objectionable eventuality in the eyes of the engineering designer. Since it was mainly an enquiry into the conditions of rupture which prompted the experiments reported in this paper, it is desirable to summarise and discuss the established facts relating to rupture.

In a brittle material like cast iron there are, by common acceptance,[3] two distinct criteria of rupture, tensile stress and shear stress. If the normal stress across any surface exceeds a certain tensile value rupture occurs along that surface; if the tangential stress on any surface exceeds another certain value rupture occurs

[1] H. Lode, *Mitteilungen über Forschungsarbeiten auf dem Gebiete des Ingenieurwesens*, 1928, No. 303. Taylor and Quinney, *Philosophical Transactions*, 1931, A., vol. 230, p. 323.

[2] Ludwik and Scheu, *Stahl und Eisen*, 1925, vol. 45, p. 373. Siebel and Pomp, *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1927, vol. 9, p. 157.

[3] *But see* A. A. Griffith, *Philosophical Transactions*, 1921, *A.*, vol. 221, p. 163. P. W. Bridgman, *Journal for Applied Physics*, 1938, vol. 9, p. 517.

along that surface. Since the limiting shear stress for cast iron is roughly twice the limiting tensile stress, failure under tensile loading or under torsion occurs by tension across the appropriate principal tensile surfaces, while under compressive loading rupture occurs by shear along surfaces of greatest effective shear stress.

In a ductile material it is the general opinion that rupture occurs by shear. In a tensile test the familiar cup-and-cone fracture bears clear evidence of sliding at the instant of rupture, and in torsion the surface of rupture is a transverse plane of maximum shear stress.

But it is a proved fact that the process of rupture at the neck of a ductile bar in tension always commences inside the material across what is substantially a plane of maximum tensile stress,[1] and that shear sliding on the cup-and-cone surfaces continues to a measurable extent after fracture has been initiated.

Under ordinary conditions of fatigue, where plastic strain is insignificant, it is perhaps natural to expect that the conditions of ultimate fracture should be more similar in type to those of elastic breakdown, but it is significant that failure appears to develop either along surfaces of maximum tensile or along surfaces of maximum shear stress according to circumstances. In alternating bending or direct stress fracture develops across a plane of principal tensile stress, while in alternating torsion failure develops on either or both sets of planes of complementary maximum shear stress.[2]

It would therefore appear that the rupture of a ductile material like mild steel might be determined by alternative criteria similar to those for brittle materials, and occur either when the normal stress reaches a certain limit or when the shear stress reaches another limit. But this hypothesis cannot be complete in itself, for it does not explain two facts well established for mild steel :

(1) Under static torsion rupture always occurs across a transverse plane and not along a longitudinal plane through the axis, although these sets of planes are subject to equal shear stress. Under torsional fatigue conditions this preference does not appear to exist.

(2) The shear stress at which rupture occurs in static torsion (about 25 tons per sq. in.) is considerably less than that (upwards of 30 tons per sq. in.) which is withstood successfully under static tension, even though this latter is combined with an equal tensile stress. Under torsional fatigue, on the

[1] P. Ludwik, *Zeitschrift für Metallkunde*, 1926, vol. 18, p. 269. C. W. MacGregor, *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1937, vol. 124, p. 218. B. P. Haig, *Proceedings of the First International Congress for Applied Mechanics*, 1924, p. 326, who, however, attributes fracture to " triple tensile stress."

[2] Gough and Pollard, *Proceedings of the Institution of Mechanical Engineers*, 1935, vol. 131, p. 41.

other hand, the limiting shear stress is somewhat greater than the corresponding shear stress under direct or bending fatigue.

Since the principal respect in which fatigue breakdown differs from static breakdown is in the absence of any considerable degree of plastic flow, it seems reasonable to suspect that the differences in type of fracture between static and fatigue conditions are due in some way to the effects of plastic strain. In order to examine the implication of the static comparisons it is necessary to consider the stress and strain conditions which develop under torsion and tension.

Strains in Torsion and Tension.

Fig. 1(*a*) represents a circular bar in torsion and Fig. 1(*b*) shows the system of simple shear stress to which it is subject. During

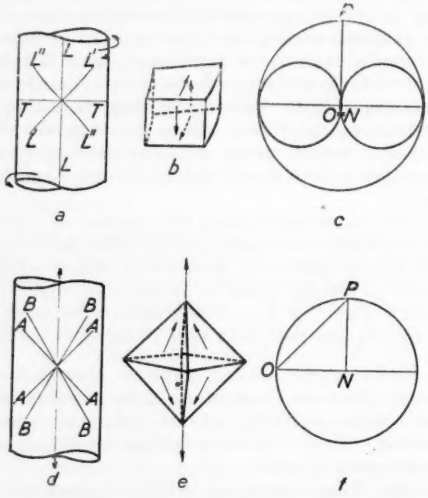


FIG. 1.—Stress Systems in Tension and Torsion.

the process of twisting, transverse planes *TT* are always subject to the principal shear stress, and particles lying in these planes continue to lie in these planes throughout the process of twisting. Longitudinal planes *LL* are subject to the same principal shear stress, but particles lying initially in these planes become displaced during twisting into a surface of which the trace is the helical line *L'L'*, while other surfaces are sheared into the planes *LL*. Hence elementary surfaces lying in planes *TT* are subjected to the

maximum shear stress and partake of the maximum shear strain throughout the process of torsion, while longitudinal planes *LL* rotate into positions where the shear stress (in relation to the maximum) is progressively lower until, if torsion continues to the point where the external shear strain is unity, so that the angle between *LL* and *L'L'* is 45°, they become relieved of all their shear stress and are subject to compression only. At the same time the surfaces which finally occupy the plane *LL* were initially subject to pure tension without shear. It is therefore clear that, by comparison with transverse planes, longitudinal diametral planes are not subject to such persistent severity of shear stress and shear strain during the process of twisting. The fact that rupture in torsion always occurs on a transverse plane *TT* suggests therefore that severe sliding tends to develop a weakness in shear strength.

In the case of a bar in tension (Fig. 1(*d*)) all planes making an angle of 45° with the axis of tension are subject to the principal shear stress (Fig. 1 (*e*)), but all these planes, and indeed all planes subject to any shear stress, rotate during the process of axial strain, so that no row of particles in the bar is subject to continuous maximum shear stress and strain. The greater ability of the material to withstand rupture in shear under tensile as compared with torsional conditions is consistent with the hypothesis that slide reduces shear strength.

In advancing this hypothesis it is not forgotten that, since any plastic strain is essentially a compound shear strain or slide, the effects of shear strain cannot differ from those of plastic strain generally. The most evident effect of plastic strain on such a material as mild steel is an increased resistance to further strain in the same direction, and strain-hardening of this kind is, of course, produced by sliding under pure shear. But resistance to strain is not synonymous with resistance to rupture, and conditions which increase resistance to strain do not necessarily increase resistance to rupture. It is therefore not irrational to suggest that, while overstrain increases resistance to distortion, it reduces resistance to rupture in shear.

The conditions of rupture in a torsion bar show, moreover, that this reduction may be directional in character and therefore indicate that shear strain tends to make a material anisotropic in the matter of strength. Since shear strains are themselves essentially directional in character, this suggestion is not irrational, and, since all plastic strain is the product of directional components, it leads to the further suggestion that plastic strain generally destroys the strength-isotropy of a material.

Mechanism of Breakdown.

It is possible to form something of a speculative picture of the mechanism underlying these effects of plastic strain, which is consistent with certain familiar conceptions of crystal distortion.

When a crystalline aggregate is subject to shear, slip occurs principally in those crystallites which have favourably disposed glide-planes, and develops along these glide-planes. The distortion of the lattice structure caused by this sliding produces discontinuities in the mosaic blocks, which are broken from their lamellæ, rotated and eventually broken into smaller fragments, particularly near the crystal boundaries, in the general manner illustrated in Fig. 2. The consequent geometrical disconformities induce rotation, distortion and partial fragmentation in other crystallites. The

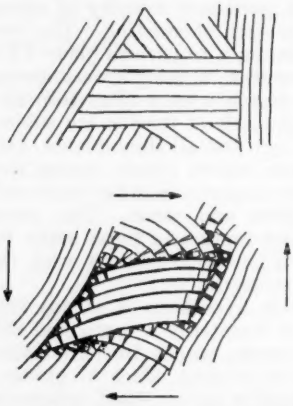


FIG. 2.—Disintegration at Grain Boundaries.

disturbance of the lamellar regularity produces increased resistance to further sliding, but the progressive disintegration of the mosaic structure weakens the resistance to rupture of those crystallites in which distortion has principally occurred. Since these crystallites are the ones of which the glide-planes were favourably disposed for slipping under the applied shear stress, the weakening of the resistance of the material as a whole to rupture occurs mainly along the planes of severe shear strain.

Scheme of Experimental Work.

For the purposes of exploratory investigation of the plastic behaviour of a material under different systems of stress and of the effect of plastic distortion on its mechanical strength, the two most convenient and elementary systems of stress are simple tension and simple shear. It has already been pointed out that under neither of these systems do planes remain in similar geometrical relationship during continued strain, but since all plastic strain is distortional in character, the simplification which such a

relationship would provide is unattainable by any system of stressing.

The direct relationships between stress and strain and the circumstances of rupture in simple tension and simple torsion are well known, so that the influence of plastic strain under one system on subsequent plastic strain and resistance to rupture under continued application of the same system can also be regarded as known. But the influence of plastic strain of one type on the behaviour of material under subsequent stressing of another type does not appear to have been studied. The effect of severe overstrain in torsion on the behaviour of a material in tension is a simple case in point which must necessarily conform to any satisfactory general theory. For this reason a scheme of experimental work was undertaken in order to ascertain the effects of severe torsional overstrain on the tensile properties of mild-steel.

The form of specimens for this work was determined by the importance of following the stress and strain conditions under tensile test beyond the point of maximum load and right up to the point of rupture. Since as much as 80% of the local plastic strain occurs during the necking period, which commences at the point of maximum load, measurements during this period are of special importance in obtaining stress-strain characteristics, and since the strain is then essentially local it can only be computed from measurements of cross-section. Specimens of tubular section, although they would provide more uniformly strained material under torsion, are impracticable where measurements of cross-section have to be made during necking and at fracture. Moreover it is difficult to maintain axial truth of a tube under severe torsional overstrain. For these reasons test-pieces of solid circular section were chosen for this particular enquiry; reliable and accurate experimental measurements could then be made and the effects of non-uniform shear-stress distribution could be allowed for with sufficient accuracy for most purposes.

The test procedure was simple. A number of mild-steel bars of 1 in. square section were turned down to 0·75 in. in dia. over a sufficient length to permit measurements on a 5-in. gauge length. The ends were left square for convenience of gripping in torsion. The bars were next twisted through various angles within the plastic range up to the point of imminent fracture. They were then turned down to a parallel diameter of 0·6 in. over the gauge length of 5 in., in order to ensure axial truth, and were finally subjected to an ordinary tensile test in a machine with autographic attachment. As a basis for comparison certain bars were tested to destruction in torsion and others in direct tension without previous twisting.

Two separate series of bars were tested, obtained from quite different sources, the second series of tests being intended as a confirmation and extension of the first. The bars were all in the

fully annealed condition at the commencement of the tests and their analyses were as follows :

	Series I.	Series II.
Carbon	0·06%	0·20%
Manganese	0·32%	0·660%
Silicon	Trace	0·17%
Sulphur	0·066%	0·026%
Phosphorus	0·055%	0·019%

Full metallurgical particulars of metal II. will be found in the Appendix by Mr. G. A. de Belin.

Flow Curves for Tension and Torsion.

A certain amount of useful information regarding the more fundamental stress-strain characteristics was derived from the tests in simple tension and simple torsion.

As already pointed out, it is not possible to obtain the true relationship between stress and strain under tension from measurements or autographic records of load and extension. For this purpose it is necessary to make successive measurements of the diameter of the bar during test, these measurements being made at any section up to the point of incipient necking and at the neck section subsequently. Moreover, during the period of necking it is necessary to release the load sufficiently to keep the beam of the testing machine in balance.

If P is the load supported when the measured diameter is d, then the true stress is, of course, $p = P \Big/ \left(\frac{\pi}{4} d^2\right)$, and the corresponding principal strain, based on the assumption of constant density, is $(d_0{}^2 - d^2)/d^2$, where d_0 is the initial diameter of the test-bar.

A true tensile stress-strain curve obtained in this way is shown in Fig. 3 together with the corresponding conventional " stress-strain " diagram for purposes of comparison. The position of the point of incipient necking, indicated as P, sufficiently emphasises the importance of the range between neck formation and rupture in an investigation of plastic flow.

The torque-twist curve for the same material, shown in Fig. 4, was obtained by conventional methods. From this curve it is possible to derive a curve showing the relationship between shear stress and shear strain under simple shear conditions. On the assumption that the angle of twist is the same at all radii it can be shown [1] that the shear stress at the surface (radius R) of a solid circular bar which twists through an angle θ under a twisting moment T is :

$$s = \frac{1}{2\pi R^3}\left(3T + \theta \frac{dT}{d\theta}\right),$$

[1] A. Nádai, " Plasticity," p. 128. New York and London, 1931 : McGraw Hill Book Company, Inc.

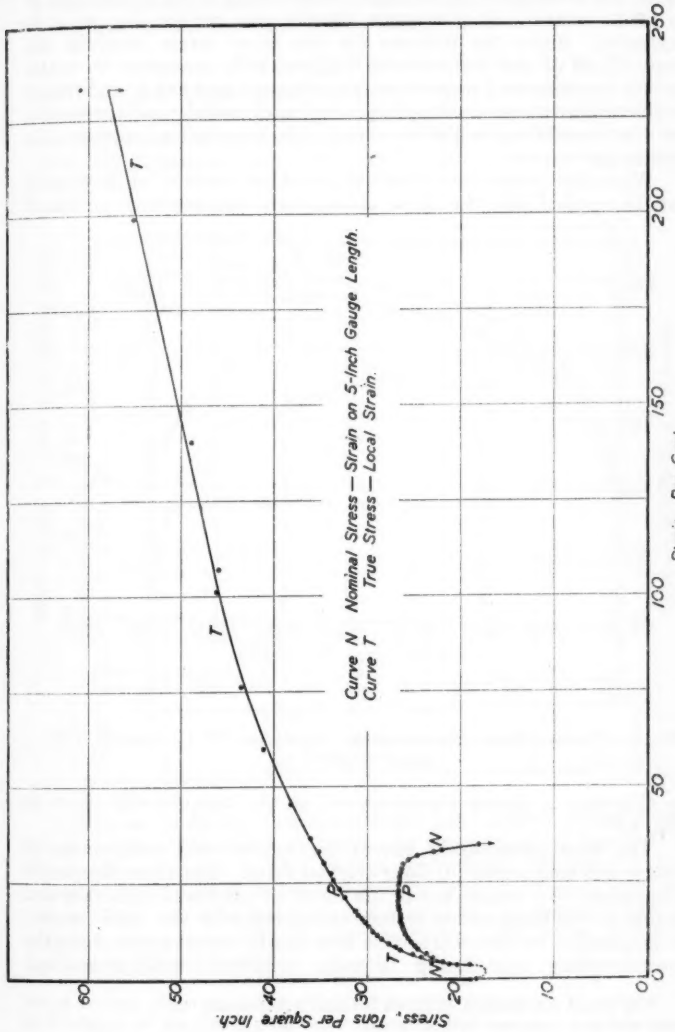


FIG. 3.—Tensile Stress-Strain Diagrams; 0·60-in. dia. mild-steel bar.

while the corresponding principal shear strain is, of course, $\tan \phi = R\theta/L$, where L is the gauge length over which the twist is measured. Since the formula for the shear stress involves the slope $dT/d\theta$ of the torque-twist diagram it is necessary to make careful experimental measurements of torque and twist, and owing to the rapid changes in slope in the region of initial yield the results are not considered reliable, except for descriptive purposes, in this range.

With this reservation a simple graphical method of derivation can be applied and the shear stress-strain characteristic obtained

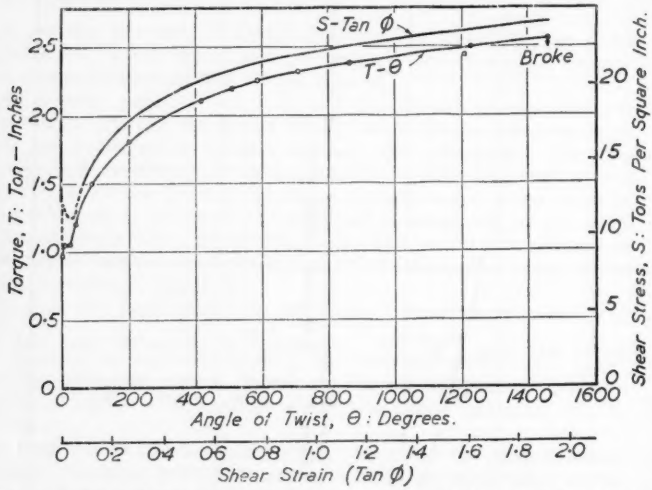


FIG. 4.—Torsional Shear Characteristic. Test-piece *TP* 1; diameter 0·75 in., gauge length 5 in.

in this way is shown superimposed on the torque-twist curve in Fig. 4.[1]

The true stress-strain curves for tension and torsion are of course not comparable in their original form. But since the plastic elongation of a tensile bar is the result of plastic shear strain and is due to the shear-stress system associated with the axial tension, it is possible to derive from the true tensile stress-strain curve the corresponding relationship between principal shear stress and

[1] A direct comparison between a shear stress-strain curve derived in this way and one obtained from a specimen carefully bored out to tubular form showed an entirely satisfactory agreement. But since these tests were not made on the particular mild steels referred to in the paper the results are not plotted.

principal shear strain. The principal shear strains corresponding to a linear strain $e = (d_0^2 - d^2)/d^2$ are given by :

$$\tan \phi = \tfrac{1}{2}\{(1 + e)^{\frac{3}{2}} - (1 + e)^{-\frac{3}{2}}\},$$

and the principal shear stresses are, of course, $s = \frac{1}{2}p$.

The shear relationship obtained in this way under tensile conditions invites direct comparison with the shear stress-strain relationship obtained under torsion and such a comparison is made in Fig. 5.

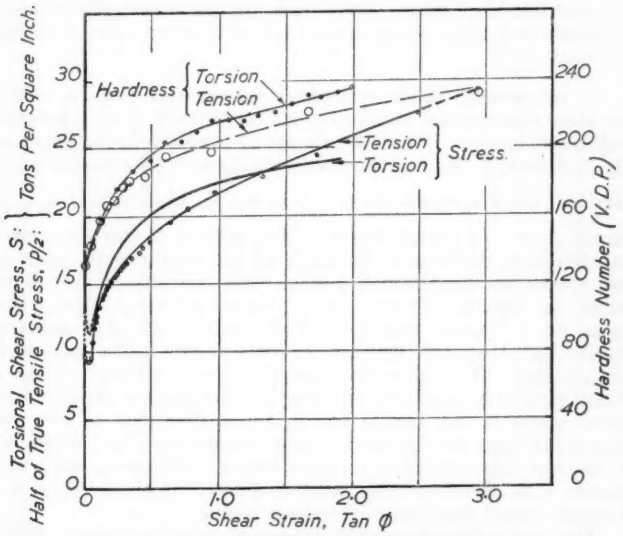


FIG. 5.—Shear-Stress/Strain Characteristics in Tension and Torsion.

Without pursuing this comparison into greater detail than is justified, it is clear that although the two curves lie together in a general way, they reveal certain systematic differences. Since similar differences have been shown by tests on another mild steel from which torsion specimens were bored out to tubular form, the results are considered as representative. The most significant points of difference are :

(1) The principal shear stresses at initial yield are not the same. According to the shear-strain energy hypothesis of elastic breakdown the yield stress in simple shear should exceed the semi-yield stress in tension in the ratio $\sqrt{\frac{4}{3}}$. Actually the

ratio appears to be greater, but since small departures in linearity of the torque-twist curve would affect the figure for shear stress at torsional yield to a considerable extent no great significance is attached to the discrepancy.

(2) During the earlier stages of plastic strain the torsion system of stress produces less strain than the tension system.

(3) Under more severe plastic strain the tension system produces a greater rate of strain-hardening than the torsion system.

(4) Under the tension system the material is capable of withstanding more strain and higher shear stress and of absorbing more strain energy per unit volume before ultimate rupture.

In considering these differences reference should be made to the three-dimensional stress systems corresponding to simple shear and simple tension. These are shown by the Mohr circle diagrams in Fig. 1, (*c*) and (*f*). For a given maximum shear stress s in each case, the principal shear stresses are s, s, o in simple tension and s, $\frac{s}{2}$, $\frac{s}{2}$ in simple shear. A tensile bar is in fact subject to full shear stress s on all planes inclined at an angle of 45° to the axis, while only two planes passing through a given point are subject to full shear stress in torsion. Consequently, while principal shear strains occur on a "single infinity" of planes through any point in a tensile bar, they are confined to two perpendicular planes in a torsion bar. It is possible that this quite different stress and strain geometry accounts at once for the greater strain under a given stress in the tensile bar in the earlier part of the plastic region and also for the greater strain-hardening effect which tends to reverse this condition in later stages. Whatever may be the reason, it is clear, however, that resistance to plastic shear is not a single valued function of the shear strain.

The possibility that this resistance might correlate with the strain energy can be examined from the data available. The strain energy under simple shear is $\int s\, d(\tan \phi)$ while that under simple tension is $\int (p\, de/(1 + e)) = \int p\, d \log (1 + e)$, where p is the true tensile stress. In Fig. 6 curves are shown in which s is plotted against $\tan \phi$ (as in Fig. 5) and p against values of $\log (1 + e)$ (derived from Fig. 3). The strain energy required to produce the resistance to plastic strain corresponding to any ordinate NP is measured by the area ONP below the relevant curve up to that ordinate. It will be seen (curves A and T) that the relationship is substantially different under the two systems of stress, so that resistance to plastic strain is not a single-valued function of the strain energy.

Measurements of hardness taken on the surface of torsion and tension bars at various stages of overstrain will be found plotted in Fig. 5. In the case of the torsion bar these measurements

correspond to the surface for which the stress-strain curve is computed and should therefore be representative. In the case of the

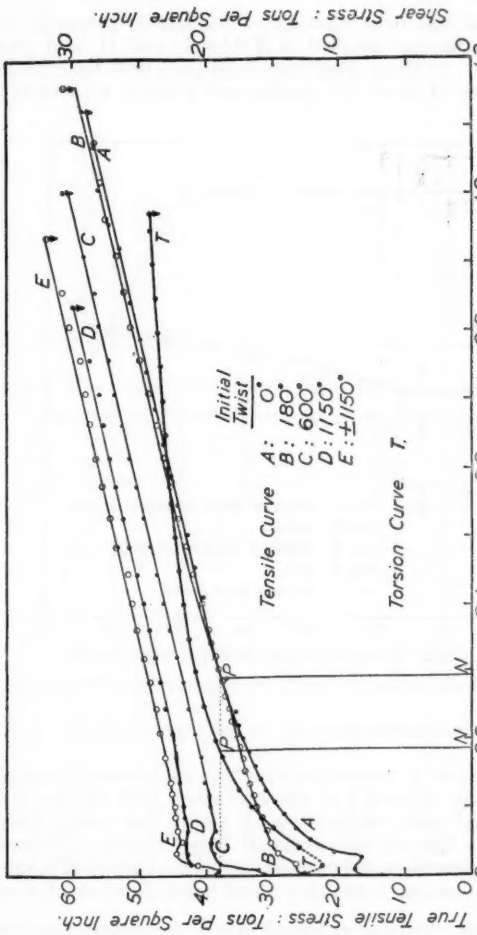


FIG. 6.—Generalised Stress-Strain Relationships.

tensile bar it is known that hardness varies across the section of the neck to an increasing extent as necking proceeds so that the

representative hardness will probably be somewhat lower than that measured.[1]

Tension after Torsion.

The principal test data relating to the tensile properties after torsional overstrain are detailed in Tables I. and II. and plotted in Figs. 7 and 8. In those cases where complete data were obtained from both series of tests the results are plotted separately; in

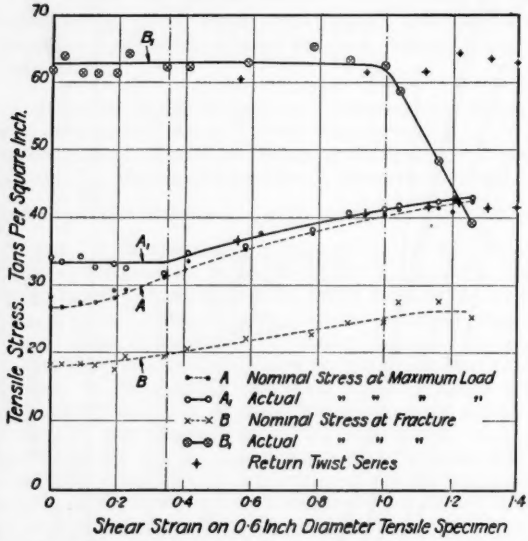


FIG. 7.—Significant Values of Tensile Stresses in Torsion-Tension Tests.

other cases the measurements refer to the second series, which was more complete.

In Fig. 7 curve A represents the " ultimate tensile strength " as conventionally defined, *i.e.*, the maximum load divided by the original sectional area, while curve B shows the actual breaking load divided by the original sectional area. Curve A_1 shows the actual stress measured on the reduced area at the instant of maximum load, *i.e.*, when necking commences, and curve B_1 shows the actual

[1] Although the probability of error is greater in hardness than in stress determinations, the curves indicate, and results obtained at different times with other bars confirm, that the hardness is not a single-valued function of the shear strain or of the strain energy, nor is it a criterion of incipient rupture. For evidence on this last point reference may be made to Table V.

TABLE I.—*Results of Torsion-Tension Tests. First Series.*

Gauge length 5 in. Torsion bar 0·75 in. in dia. Tensile bar 0·60 in. in dia.

Mark.	Initial Twist.		Tensile Test.					
					Nominal Stress.			
	Angle. Degrees.	Torque. Ton-in.	External Shear. Tan θ.	Vickers Diamond Pyramid Hardness.	At Max. Load. Tons per sq. in.	At Fracture. Tons per sq. in.	Reduction of Area. %.	Extension on 5 in. %.
*A*1 . .	...	...	...	105	23·32	15·1	69	37·2
*A*2 . .	74	1·185	0·092	...	23·45	16·2	70·6	31·0
*A*3 . .	91·5	1·35	0·114	134	25·32	17·3	67·6	28·4
*A*11 . .	136	1·59	0·164	149	29·12	19·6	66·2	15·2
*A*4 . .	189	1·59	0·229	151	25·88	17·3	68·65	15·2
*A*9 . .	270	1·86	0·330	177	30·65	19·7	65·4	11·6
*A*5 . .	365	1·845	0·447	159	30·2	17·8	66·15	10·4
*A*7 . .	560	1·98	0·680	173	34·22	20·0	63·35	8·8
*A*6*X* .	720	2·124	0·880	191	36·42	21·2	61·95	8·0
*A*6 . .	721	2·1	0·871	185	36·8	20·6	62·1	8·4
*A*14 . .	921	2·22	0·964	217	37·9	21·8	59·7	7·8
*A*8 . .	1,080	2·223	1·302	198	39·75	25·6	10·44	3·0
*A*10*X* .	1,530	2·61	1·335	242	49·55	49·5	3·97	3 on 2 in.

TABLE II.—*Results of Torsion-Tension Tests. Second Series.*

Gauge length 5 in. Torsion bar 0·75 in. in dia. Tensile bar 0·60 in. in dia.

Mark.	Initial Twist.		Tensile Test.					
					Nominal Stress.			
	Angle. Degrees.	Torque. Ton-in.	External Shear. Tan θ.	Vickers Diamond Pyramid Hardness.	At Maximum Load. Tons per sq. in.	At Fracture. Tons per sq. in.	Reduction of Area. %.	Extension on 5 in. %.
TPX .	Nil	...	0	134	26·9	18·2	70·6	32
*TP*2 .	29	1·05	0·030	138	26·9	18·4	71·2	28·8
*TP*3 .	86	1·41	0·090	150	27·5	18·2	70·5	28·4
*TP*11 .	129	1·65	0·135	162	27·4	18·7	69·5	24·8
*TPP*1 .	183	1·86	0·192	169	29·2	19·2	68·6	23·0
*TP*4 .	185	1·8	0·194	169	28·1	17·8	71	24·8
*TP*4*R* .	215	1·8	0·225	173	29·4	19·3	70	17·6
*TP*5 .	290	1·95	0·304	176	31·0	19·3	69	13·2
*TP*6 .	392	2·1	0·410	192	33·5	20·6	67	11·2
*TP*7 .	557	2·22	0·584	205	35·4	22·0	65	8·0
*TPP*2 .	600	2·33	0·628	200	37·6	22·45	63	9·3
*TP*8 .	756	2·31	0·792	200	37·8	22·8	65	8·0
*TP*10*A* .	850	2·43	0·890	212	40·3	24·3	61·5	8·0
*TP*15 .	932	2·49	0·975	220	40·5	24·6	60·6	6·4
*TP*14 .	994	2·46	1·04	223	41·2	27·6	53	6·0
*TP*9*A* .	1,103	2·56	1·16	223	41·4	27·5	43	6·6
*TPP*3*R* .	1,150	2·49	1·20	212	40·7	25·3	28	5·4
*TP*13 .	1,206	2·55	1·26	224	42·2	25·1	36	5·6
*TP*1 .	1,458	2·55	1·52	Broke in torsion.				

stress at the moment of rupture, being based on the actual breaking load and the sectional area across the broken neck. It is evident that for purposes of scientific enquiry curves A_1 and B_1 are more significant than the others, though there is a possible error involved

in the measurement of the sectional area at rupture. This fact was revealed during certain later tests in which continuous micrometer measurements were made at the neck right up to fracture. It was found that after fracture had commenced (internally), as proved by the sudden drop of the beam of the testing machine, a certain amount of drawing continued in the unbroken outer annular ring and the diameter at the neck after complete separation was

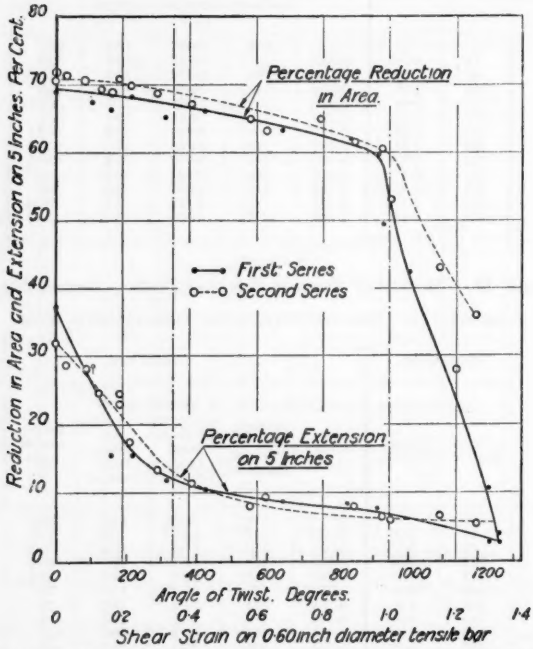


FIG. 8.—Extension and Reduction of Area; Torsion-Tensile Series.

measurably less than that when the fracture commenced. The stress values plotted in curve B_1 are therefore probably somewhat high, though no more in error than the general spread of the plotted points.

For the same reason the percentage reduction in area and percentage elongation shown plotted in Fig. 8 are also slightly high, though the errors are quite insignificant for present purposes.

In order to interpret the results plotted in Figs. 7 and 8, particularly with regard to any evidences of anisotropic behaviour, it is well to picture the behaviour under successive torsion and

tension of a (possibly hypothetical) isotropic material having stress-strain-hardness characteristics similar to those of the metal under test.

In forming this picture it is to be remembered that the true tensile stress-strain relationship follows a constantly rising curve on which the "maximum load," which corresponds to incipient necking, has no special significance *per se*, but merely marks the point at which the material begins to attenuate at a greater rate than its specific resistance to strain increases—in other words, where its length begins to increase more rapidly than its strength. At this point the hardness number of the metal is about 182, and as the material in the neck continues to stretch its hardness increases with the tensile stress until it reaches a value of about 230 and the stress attains about 60 tons per sq. in., when final rupture occurs.

If the material is subjected to torsional shear instead of tension its passage through the point of hardness 182 is without incident and occurs, as will be seen in Fig. 5, at a comparatively early stage of torsional strain. At points beyond this the material will be in a condition generally similar to that in the neck of a partially necked tensile bar, with some reservation due to the fact that the hardness is not uniform across the section in either case.

If the material, after submission to torsional shear to a hardness less than 182, is subjected to a tensile test it would, if isotropic, be expected to behave in the same way as a specimen of the same material which had been initially overstrained in tension to such a load, less than the maximum, as would produce the same hardness number. In this case the general extension would be reduced, the true stress at incipient necking unaltered and the reduction of area during the process of necking unaffected.

If the same material were subjected to torsional shear to a hardness greater than 182, then it should behave in a subsequent tensile test similarly to a portion from the neck of a tensile specimen of the same material which had been initially overstrained until partially necked (to the requisite hardness). In this case there would be no general extension, the actual stress at incipient necking would be raised and the reduction of area during necking would be less pronounced, because strain corresponding to a certain degree of necking had already occurred in the initial twisting.

The general form of the fracture would be similar in all cases.

Typical autographic diagrams obtained from tensile bars with various degrees of initial torsional overstrain are shown in Fig. 9.

In order to ascertain to what extent they are in agreement with the speculations just evolved, the autographic diagrams can be converted with advantage into a more comparable form. For this purpose it is first necessary to ascertain the appropriate initial linear strain corresponding to the preliminary torsional treatment, *e.g.*, by correlation of hardness numbers, and it is then necessary to

correct the elongation values to conform to the laws of geometrical similarity.

Since the degree of overstrain varies across the section of a solid bar in torsion an effective mean value for the hardness must be found for correlation with the tensile test. Since the shear strain at any point is proportional to its distance from the axis and since the hardness follows an approximately parabolic law in relation to

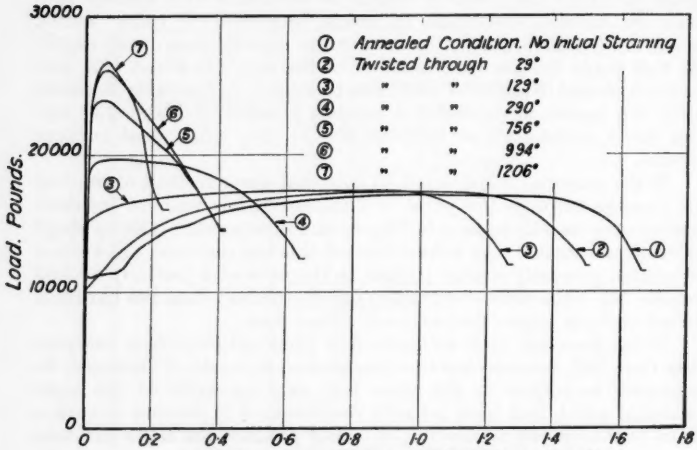


FIG. 9.—Autographic Tensile Test Diagrams for 0·60 in. dia. Bars; Torsion-Tension Series.

shear strain the mean hardness across a section overstrained in torsion may be estimated as :

$$h = \int_0^R \frac{h 2\pi r dr}{\pi R^2} = \frac{2}{R^2}\int_0^R (h_0 + cr^{\frac{1}{2}}) r dr = \tfrac{4}{5}h_R + \tfrac{1}{5}h_0,$$

with an obvious notation. For the mild steel under examination $h_0 = 134$. Hence $h = 27 + \frac{4}{5}h_R$, where h_R is the surface hardness, measured for present purposes on the surface of the turned tensile specimen (0·6 in. in dia.).

When this effective hardness has been ascertained reference to Figs. 5 and 3 shows the corresponding proportional elongation e_0 for a tensile bar and therefore the point from which the autographic diagram for the twisted bar should commence.

It is now necessary to remember that the bar initially overstrained, although actually machined identical in dimensions with an unstrained bar, is not effectively identical with it for purposes of strain measurement, for, if its actual diameter when inserted in the

tensile machine is D and its length L, then, since it had already been subjected to an effective strain e_0, it really corresponds to a partly pulled bar of which the initial diameter was $D(1 + e_0)^{\frac{1}{2}}$.

For true geometrical similarity (ratio L/D for unstrained specimens) the length of the unstrained bar should therefore have been $L(1 + e_0)^{\frac{1}{2}}$. If an unstrained bar of diameter $D(1 + e_0)^{\frac{1}{2}}$ and length $L(1 + e_0)^{\frac{1}{2}}$ had been pulled it can be shown that the total extension would have been :

$$Z = y + L(1 + e_n)\{(1 + e_0)^{\frac{1}{2}} - (1 + e_0)^{-\frac{1}{2}}\} - L\{(1 + e_0)^{\frac{1}{2}} - 1\},$$

where y = actual measured total extension to rupture on bar of length L.

e_n = proportional extension to incipient necking, determinable from parallel diameter (d) of broken specimens :

$$\left(\frac{d}{D}\right)^2 = \frac{1 + e_0}{1 + e_n}.$$

Hence the equivalent proportional elongation to be plotted on the composite autographic diagram is $Z/L(1 + e_0)^{\frac{1}{2}}$, while the equi-

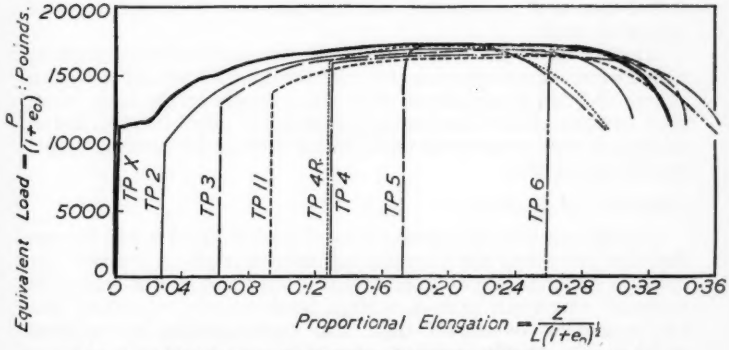


FIG. 10.—Modified Load-Extension Diagrams (following Torsion).

valent "load" referred to an unstrained bar of diameter D is $P(1 + e_0)$, where P is the actual load applied.

When this procedure is adopted with the autographic diagrams of which Fig. 9 is representative, the modified diagrams are found to compare with the original unstrained autographic curve as shown in Fig. 10. Having regard to the speculative character of some of the assumptions made, the general conformity is not unsatisfactory, but there is a systematic tendency towards low yield stresses and a considerable spread in the unstable region where the load falls after necking.

Since yield in tension can only occur when all fibres have reached their individual yield stress and since the mean hardness value is professedly representative in this respect the low yield strength

after torsional overstrain cannot be ascribed to soft metal at the core or any similar non-uniformity. Moreover, if the average shear stress across the section under the preliminary torsional overstrain (estimated by a similar method to the mean hardness) is compared with the shear stress at subsequent yield in tension it is found that, provided the torsional overstrain is carried well beyond the yield point, the ratio of the semi-yield stress to the preliminary torsional shear stress is less than that predicted by the shear-strain energy theory of elastic breakdown by roughly 10%.

It is more likely therefore that the discrepancy is attributable to the effect of the internal-stress system residual after the removal of the torsional overstrain. This system would, of course, give rise to higher average stresses in the tensile bar than those due to the tensile load and would therefore lead to an early yield. If the torsional stress due to overstrain is assumed uniform it can be shown that due to internal stress the yield point in tension will be lowered by 7% or more. After subsequent overstrain in tension this effect would gradually become masked, and the autographic curves should then tend to converge, which in fact they do in the region of maximum load.

The spread of the curves in the mechanically unstable necking region involves the question of actual breaking stress and reduction of area and can be considered more convincingly on the basis of the more complete direct measurements plotted in Figs. 7 and 8, and in relation to true stress-strain tests carried through the necking period and discussed later.

Conditions of Rupture.

Considering first the stress values plotted in Fig. 7 it will be seen that the true stress when necking commences (curve A_1) varies very much in accordance with expectation. For those bars in which the torsional overstrain gave a surface hardness not exceeding 182, *i.e.*, a smaller overstrain than that corresponding to incipient necking in a tensile specimen, the stress at incipient necking is unaltered. On the other hand bars overstrained in torsion beyond this point correspond to material in a partially necked tensile specimen and therefore neck at a higher stress corresponding to that in the partially formed neck of the tensile bar.

Also in accordance with expectations the true ultimate stress at rupture (B_1) is practically the same (about 63 tons per sq. in.) whether the bar has been previously overstrained or not, provided the overstrain does not exceed a certain value. But overstrain beyond this point, which corresponds to a surface shear strain of about 1·0 on the tensile specimen, produces a marked and progressive diminution in the rupture stress.

Referring now to the reduction of area plotted in Fig. 8 it will be seen that the attenuation is progressively reduced by increasing torsional overstrain. When the material at the commencement of

the tensile test is already overstrained it is effectively in a partly drawn condition, and it is therefore more informative for present purposes to consider the reduction of area which occurs during the process of necking. This is of course obtainable from measurements of the parallel portion and necked portion of the broken tensile bar and the values are plotted in Fig. 11. From this it will be seen that there is very little difference in the " necking ratio " over the whole range of torsional overstrain up to the limit already noted, but beyond

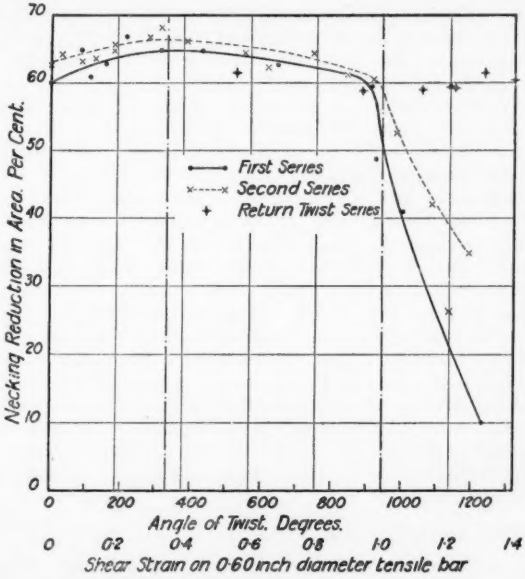


FIG. 11.—Reduction of Area due to Necking.

this point the attenuation falls away very rapidly, in a similar way to the rupture stress.

These remarkable and apparently sudden changes beyond the torsional overstrain giving unity surface shear are accompanied by a change in the type of fracture. Instead of the conventional cup-and-cone type which is produced unimpaired up to this point, a " wolf-ear " type of fracture (Fig. 13) is produced of a form which shows that rupture has developed on surfaces making helical angles of approximately 45° with the axis of the bar. The fracture has a rather brittle appearance (consistent with reduced attenuation) and cracks on the outer surface extend in the 45° direction for some little distance from the section of fracture. This fracture is clearly due

to shear on those planes which are subject to maximum shear stress under tension and which were subject to severe shear overstrain under the preliminary torsion.

These results are entirely in conformity with the mechanism of rupture suggested earlier in the paper. In a tensile bar which necks and breaks with a cup-and-cone fracture in the usual way, the fracture commences on a transverse plane subject to tensile but no shearing stress. Hence it may be said that fracture occurs by tension and (on the testimony of Fig. 7) at a tensile stress of about 63 tons per sq. in. Since no diminution in this stress is produced by previous torsional overstrain up to the critical point (of unity surface shear strain) it seems clear that the strength of the transverse planes against tensile stress is unaffected by the severe shear stress and overstrain to which they were continuously subject under torsion and which had demonstrably reduced their shear strength. Since fracture in the neck of a previously unstrained tensile bar does not initiate by shear, the shear resistance of the material in the neck along surfaces of principal shear stress must under these conditions exceed $\frac{1}{2} \times 63$ tons per sq. in. Preliminary torsional strain progressively reduces the shear strength of the material, albeit to a different extent in different planes, until, when this overstrain corresponds to an external shear of about unity, the shear strength along the 45° helical " planes " becomes less than $\frac{1}{2} \times 63$ tons per sq. in. so that rupture occurs by shear on these " planes " instead of tension on transverse planes; it occurs at a diminished stress and at a relatively early stage in the necking process. The sudden change in breaking stress at the critical degree of initial overstrain does not therefore connote any fundamental discontinuity but arises from the intersection of the falling " shear strength " curve with the constant " tensile strength " line. The sudden change in attenuation is of course consequential.

True Stress-Strain Curves.

The rather considerable spread of the adjusted autographic curves in Fig. 10 beyond the point of maximum load opens the question as to whether the inherent stress-strain characteristics of the material were changed by torsional overstrain. On this point the autographic curves themselves are not strong evidence, for they were adjusted by the help of hardness as a correlating parameter, and this method cannot be better than approximate; for hardness measurements are themselves subject to accidental and personal errors, casual differences in hardness occur even between similarly disposed points on a single overstrained specimen, and systematic changes in hardness are relatively small over the wide region on the autographic diagram corresponding to maximum load. The inexactitude of hardness as a correlating parameter is illustrated by the numerous comparable observations made during the series of tests on metal II. which are plotted in Fig. 12.

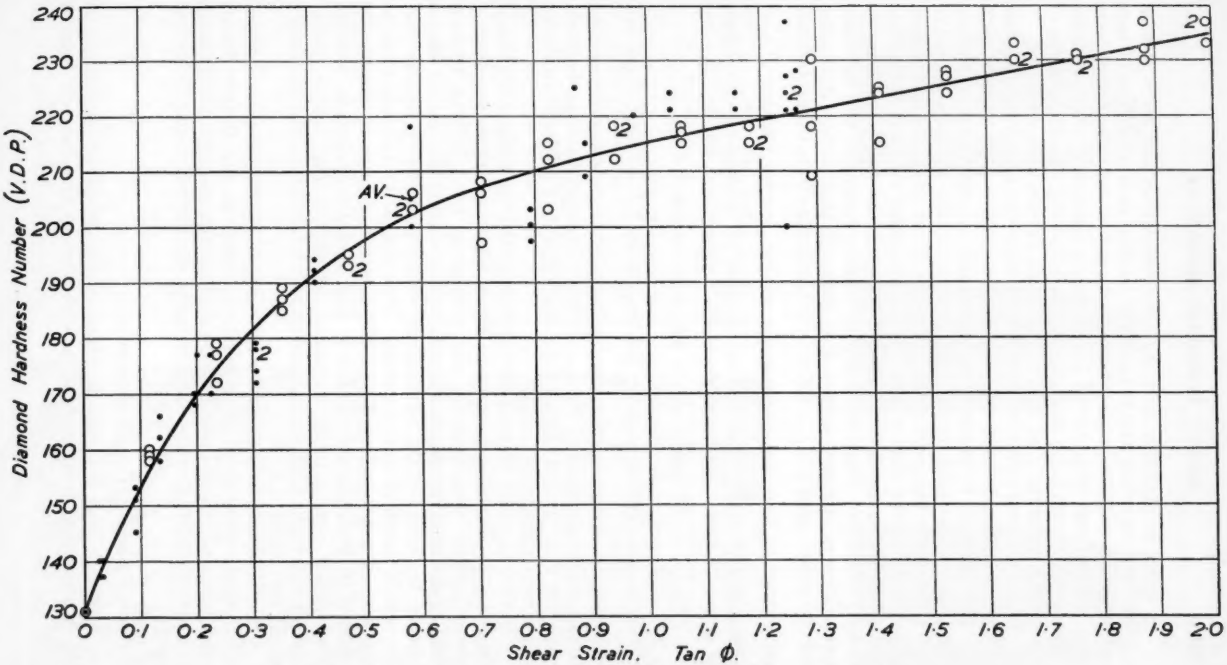


FIG. 12.—Shear-Strain/Hardness Relationship for Mild Steel in Torsion.

In order to obtain a more reliable correlation and more precise information regarding the tensile stress-strain characteristics of bars subjected to initial torsional overstrain, a few supplementary tests were carried out with metal II. in which diameter measurements were made throughout the tensile test following various degrees of torsional overstrain, and true stress-strain curves were deduced.

The true linear strain at a section of which the measured diameter is d and the unstrained diameter was d_0 is $e = (d_0^2 - d^2)/d^2$. But for the purpose of comparing previously overstrained specimens the proper value of d_0 is not that (0·6 in.) at the commencement of the tensile test but rather the diameter of an unstrained specimen which would have drawn down to the diameter d_0 when it reached the condition in which the overstrained specimen was inserted in the testing machine. Bars with various initial overstrains will therefore have different effective values of d_0 although their actual diameters are the same, namely, $d_1 = 0{\cdot}6$ in. If the stress-strain characteristics of a series of bars are intrinsically similar, curves relating $P \Big/ \frac{\pi}{4} d^2$ with $e = (d_0^2 - d^2)/d^2$ should be identical if the appropriate values of d_0 are chosen. Moreover since the "generalised strain" is:

$$\log (1 + e) = 2 \log d_0 - 2 \log d,$$

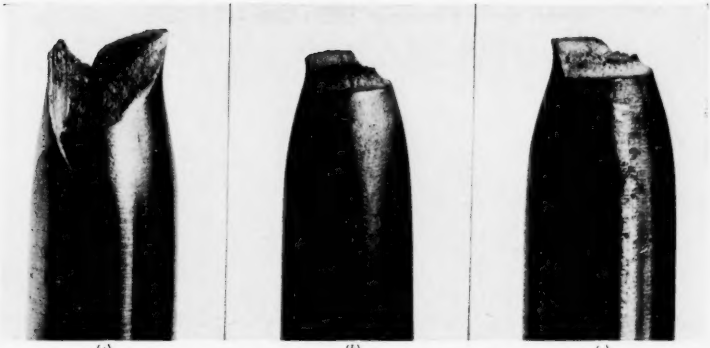
it follows that curves relating the true stress $P \Big/ \frac{\pi}{4} d^2$ with $\log d$ will be similar in shape and merely displaced by amounts corresponding to the different values of $\log d_0$. Hence similarity in shape between curves of P/d^2 plotted against $\log d$ is a criterion of intrinsic similarity of stress-strain characteristics.

Curves in which this relationship is plotted for various degrees of torsional overstrain are shown in Fig. 6 added to the corresponding curve (already discussed) for the unstrained bar. It will be seen that apart from transient disconformities during the earlier stages of test, the forms of the various curves are remarkably similar over the whole range of initial twists. This similarity extends even to the case of a bar (referred to later) which had been so drastically twisted in both directions that it had actually broken in torsion. Since after considerable tensional overstrain the earlier strain history of a bar is likely to be masked to a large extent, the similarity is not surprising.

It will be observed that over the range of necking the stress-strain relationship plotted in this particular way is practically linear, signifying that at any point in this range a given proportional increase in length involves the same increment in specific resistance to further strain.

Torsion Following Tensile Overstrain.

Although it is not easy to obtain such complete particulars of the stress-strain relationships involved as in the case of tension



(*a*) (*b*) (*c*)

Initial twist: (*a*) 1150°; (*b*) nil; (*c*) ± 1150°.

FIG. 13.—"Wolf-Ear" Type of Fracture (*B*), showing that rupture has developed on surfaces making helical angles of about 45° with the axis of the bar.

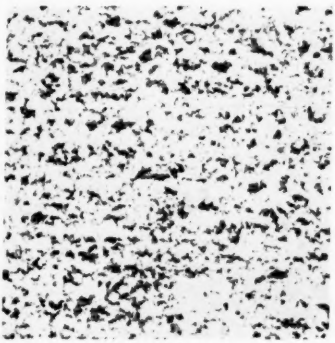


FIG. 14.—Test-Piece *TP.TH*, as Annealed. Normal Etching. × 135

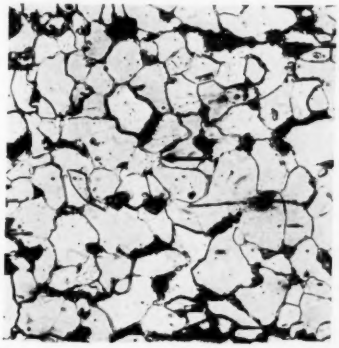


FIG. 15.—Test-Piece *TP.TH*, as Annealed. Deep Etching. × 425.

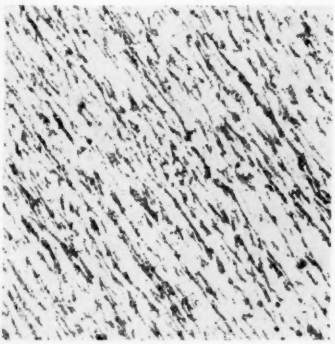


FIG. 16.—Test-Piece *TP.TH*. Torsion, + 1520°. Normal Etching. × 135.

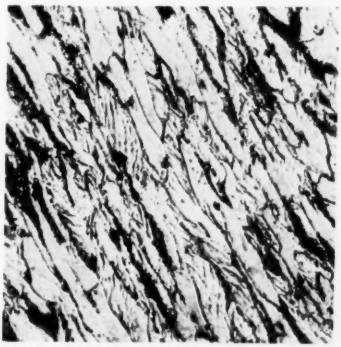


FIG. 17.—Test-Piece *TP.TH*. Torsion, + 1520°. Deep Etching. × 425.

(Illustrations reduced to four-fifths linear in reproduction.

[*Swift.*

[*To face p.* 204 P.

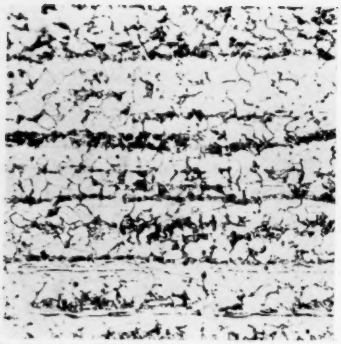


FIG. 18.—Test-Piece *TP.P4*, as Annealed. Normal Etching. × 135.

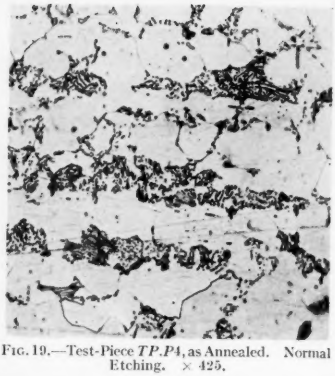


FIG. 19.—Test-Piece *TP.P4*, as Annealed. Normal Etching. × 425.

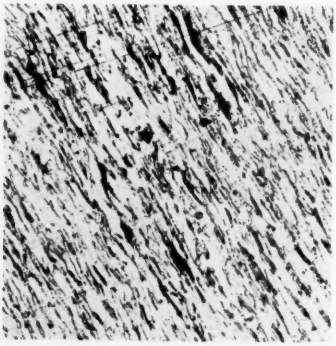


FIG. 20.—Test-Piece *TP.P6*. Torsion, + 1750°. Normal Etching. × 135.

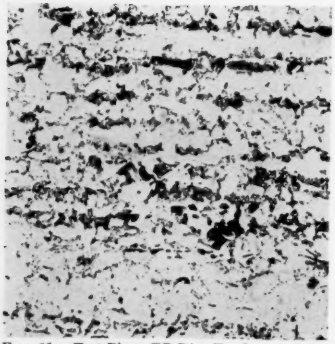


FIG. 21.—Test-Piece *TP.P4*. Torsion, + 1150°, − 1143°. Normal Etching. × 135.

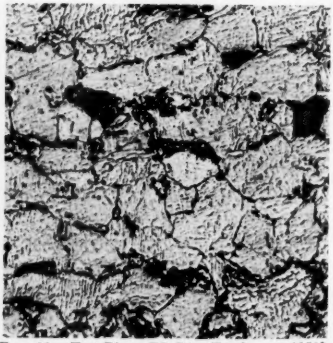


FIG. 22.—Test-Piece *TP.P4*. Torsion, + 1150°, − 1143°. Deep Etching. × 425.

(Illustrations reduced to four-fifths linear in reproduction.)

[*Swift.*

[*To face p.* 205 P.

following torsion, certain useful data regarding the conditions of rupture can be obtained from torsion tests on bars previously overstrained in tension.

Since the planes which carry the principal shear under torsion, and particularly the transverse planes, were substantially free from shear strain under the preliminary tensile action, it is to be expected, according to the hypothesis under investigation, that the shear strength of these planes would not have been impaired by this action. At the same time the tensile process would induce a general strain hardening, particularly in the neck of a partially necked specimen, and this would naturally increase the resistance of the material to *strain* in torsion. It would therefore be anticipated that under torsion the stress would rise more rapidly in relation to torsional strain and that the bar would rupture under a higher shear stress, but at the same time with less shear strain on the conical surfaces than an unstretched bar.

In order to examine this hypothesis a few tests were made (on a different mild steel from those used in the main series of tests, the supply of which had been exhausted) in which bars were pulled in tension to different stages of neck formation and then subjected to a torsion test. Failure under torsion always occurred in the neck, of course, and inspection of longitudinal lines scribed on the bars showed that the whole of the permanent twist was confined to the necked section.

The true tensile strength of the material was 55 tons per sq. in., signifying a shear strength under tensional conditions not less than 27·5 tons per sq. in. The shear strength in torsion was 22·0 tons per sq. in., accompanied by an external shear strain $\tan \phi = 2{\cdot}26$. A bar of initial diameter 0·75 in. drawn in tension to a neck 0·5 in. in dia. gave a shear strength of 25·5 tons per sq. in. with an approximate shear of 1·75, and a similar bar necked to 0·45 in. in dia. gave a shear strength of 26·6 tons per sq. in. with an approximate shear of 1·5.

The steady increase in the torsional shear strength as tensional necking proceeds is an interesting confirmation of the directional weakening effect of shear strain and of the hypothesis advanced above. The fact that considerable torsional strain can occur even after a reduction of area of 64% in tension is also a remarkable demonstration of the increase in the plastic range which can be secured by a process of distortion which distributes the shear strain over a larger number of planes, and so distributes the slip between a larger number of crystallites with differently oriented glide-planes.

Effect of Reversed Torsion.

It was thought that further light might be thrown on the effects of shear strain on resistance to rupture if tensile tests were made on material which had been distorted and subsequently restored to its

(statistically) undistorted form. A number of supplementary bars [1] of metal II. were therefore first twisted through different angles as before and then twisted back again through the same angle before being subjected to a tensile test.

It was found that the bars survived the return twist up to a point well beyond the critical stage. Bars twisted excessively failed in torsion during the return twist, but short tensile specimens were prepared from the broken bars and tested in the same way. The results of these supplementary tests are detailed in Table III. and will be found added to Figs. 7 and 11 with abscissæ corresponding to the *initial* angle of twist.

TABLE III.—*Results of Return Twisting.*

Gauge length 5 in. Torsion bar 0·75 in. in dia. Tensile bar 0·60 in. in dia.

Mark.	Twisting.			Maximum External Shear. Tan θ.	Vickers Diamond Pyramid Hardness.	Actual Stresses.		Necking Reduction in Area. %.	Extension on 5 in. %
	Initial Turns.	Return Turns.	Return Torque. Ton-in.			At Maximum Load. Tons per sq. in.	At Fracture. Tons per sq. in.		
1*X* .	1·5	1·5	2·46	0·56	203	36·5	60·3	61·6	8·8
4 . .	2·5	2·5	2·46	0·94	205	40·5	61·7	58·9	7·8
2*X* .	3	3	2·58	1·12	224	41·7	61·9	59·0	8·8
*P*4 . .	3·25	3·23 *	2·62	1·22	227	44·5	64·0	59·5	16·5 †
5*X* .	3·25	3·25	...	1·22	220	42·1	64·3	59·1	7·6
3 . .	3·5	2·5 *	2·58	1·31	206	41·2	63·5	61·6	18·0 †
0 . .	3·75	1·5 *	...	1·40	215	41·3	63·0	60·3	17·0 †

* Broke in return torsion. † On 2 in. gauge length.

It will be seen at once that return shear does not continue the effect of the initial shear. Indeed up to the critical point the effect of return shear is apparently negligible. But beyond the critical point the conditions are fundamentally changed. As might be expected the stress at incipient necking in the re-twisted bars agrees closely with that in the single-twisted bars and the general extension is negligible, but in the re-twisted bars the reduction of area is restored to its full value of 60%, the form of fracture is a perfect cup-and-cone and the true tensile stress at rupture is restored to the normal range of 60–64 tons per sq. in.

It is clear from these tests that severe reversed torsion, even up to the point of torsional fracture, does not impair the resistance of the material to tensile stress and that those helical surfaces which are left by the return twist at angles of about 45° to the axis are capable of withstanding a shear stress of over 30 tons per sq. in.

On first consideration it might appear that these facts are con-

[1] These bars had been rolled in a different manner from the first series of bars of metal II., as explained in the Appendix.

sistent with the hypothesis advanced above, for the crystallites of which the glide-planes were approximately in the planes LL (Fig. 1 (a)) before twisting and which produced the weakness on surfaces $L'L'$ after unidirectional twist, have been restored to position LL by the return twist and so relieved of stress in the subsequent tensile test, while those surfaces which occupy positions $L'L'$ after the return twist were subject to less shear stress and strain during the twisting process. But the surfaces which occupy the complementary positions $L''L''$ after the return twist must presumably have passed to the position LL and back and therefore have been subjected to conditions more severe than those which were suffered by the planes LL in passing to $L'L'$ during the initial twist and which were shown to impair their strength.

These facts appear to admit of three possible explanations :

(1) The reversal of the direction of shear strain may in some measure effect a repair of the damage caused by the initial strain. This involves an entirely new conception which does not easily conform to any current theory of strain and for which there is no collateral evidence.

(2) An internal stress system due to differential strains produced by the initial twist may have been relieved by the removal of these strains in the return twist. The existence of such a system of internal stress is almost certain in view of the non-uniform straining inherent in the torsion of a bar, since the centre fibres are distorted only slightly and will tend to restrain any tendency of the outer fibres to shrink or expand. Measurements showed that the bars increased in length under torsion, reaching an axial strain of over 2% before rupture. Hence initial twist would tend to put the outer fibres into axial compression and the centre fibres into tension. But although internal stress will no doubt modify the conditions of rupture in a brittle material and the conditions of elastic breakdown in a ductile material, it is hardly likely to affect materially the conditions of ultimate rupture in this latter case since any initial internal stresses must become completely masked by subsequent plastic strain.

(3) The material in its initial condition may not be isotropic but have planes of weakness in the axial direction. A bar consisting of a bundle of wires, for instance, would clearly be weak in tension after twisting but would have its strength restored if the wires were straightened by twisting back again. Any rolled bar is naturally predisposed to this tendency in some degree and it is noteworthy that the weakening was more marked in metal I. than in metal II. which was of " pedigree stock " and remarkably free from non-metallic inclusions.

The extent to which anisotropy was revealed by the microstructure of metal II. is discussed by Mr. de Belin in the Appendix.

Some idea of the degree of anisotropy required to explain the experimental evidence may be obtained from the results with bars twisted to give an external shear strain tan $\phi = 1{\cdot}5$. In Table IV.

TABLE IV.—*Stress Components on Representative Planes.*

Initial plane:	*L*.	*T*.	*L″*.
After twist to tan $\phi = 1{\cdot}5$	24 *c* 2·4 *s*	0 *t* 24 *s*	0 *t* 24 *s*
Subsequent tensile test	[23 *t* 21·2 *s*]	42·5 *t* 0 *s*	Nil
Early in return twist	24 *t* 2·4 *s*	0 *t* 24 *s*	0 *t* 24 *s*
At end of return twist	0 *t* 24 *s*	[0 *t* 24 *s*]	24 *c* 2·4 *s*
Subsequent tensile test	Nil	[64 *t* 0 *s*]	44 *t* 29 *s*

t = tension. *c* = compression. *s* = shear.
Plane *L″* is at 56° to plane *L*.

are shown the stress components to which three representative "planes" are subjected at various stages of the scheme of testing, and conditions of rupture are indicated by square brackets. It is notable that after the initial twist the *L* planes are not capable of carrying 23 tons per sq. in. tension with 21 tons per sq. in. shear, although the *L″* planes are capable of carrying 44 tons per sq. in. tension with 29 tons per sq. in. shear after the return twist and subsequent drawing under tension. On the other hand, if rupture occurs in torsion at the end of the return twist it occurs on the *T* planes at a shear stress of 24 tons per sq. in., although the *L* planes are subject to equal stress, and the *T* planes themselves are still capable of carrying tensile stresses up to 64 tons per sq. in. Hence, on the one hand it appears that the intrinsic weakness across longitudinal "fibres" must be considerable, while on the other hand the shear weakness developed by torsion on the transverse planes must be still more marked.

It is significant also that, although after the initial twist the *L* planes are capable of carrying a tensile stress of 24 tons per sq. in. with small shear (early in the return twist) and after the return twist are still capable of carrying a shear stress of 24 tons per sq. in., nevertheless they fail after the initial twist under a combination of 23 tons per sq. in. tension with 21 tons per sq. in. shear in a tensile test. These facts suggest that rupture may occur under a combination of tensile and shear stress in which neither component

has the maximum value which it could reach independently of the other.

Without more systematic examination of the conditions of rupture following reversal of plastic strain it would be speculative to adopt any one explanation of the results under discussion. These, it must be pointed out, were obtained from supplementary tests in the present series and left no material from the same stock with which the matter could be further explored. It is felt, however, that such exploration should be fruitful, and systematic work on another stock is being undertaken. In the meantime the available evidence is placed on record for discussion.

Conclusions.

It is felt that the results described in the paper justify the following conclusions in relation to rolled mild-steel bars of good commercial quality in the fully annealed condition :

(1) The inception of plastic flow is affected by the internal stress distribution as well as the general " scalar " condition of the material as measured, for example, by its hardness number.

(2) The relationship between shear stress and shear strain in the plastic region is not independent of the system of applied stress.

(3) The plastic stress-strain relationship under tensile conditions, although affected in its earlier stages by previous strain-history, becomes independent of this as straining proceeds.

(4) Rupture may be caused (*a*) by tensile stress, (*b*) by shear stress, or (*c*) possibly by a combination of tension and shear.

(5) Resistance to rupture by shear stress is modified directionally by overstrain. No positive evidence is furnished regarding the effect of overstrain on resistance to rupture by tensile stress, but there are indications that any such effect is small.

(6) Neither strain energy nor hardness is a controlling factor in regard to rupture, nor does either of these quantities define the resistance of the material to plastic strain in the general sense.

(7) The reversal of torsional strain has certain remedial effects on the apparent shear strength under tensile conditions, due possibly to the masking of directional properties.

Acknowledgments.

The work described in this paper was carried out as part of a programme of research on deep-drawing problems supported by the Research and Standardisation Committee of the Institution of Automobile Engineers. In the experimental work the author has received invaluable assistance from his colleagues Mr. J. F. Cartwright and Mr. J. W. Harland, and during the later stages from Mr. G. Payne, B.Eng. The micrographic work was carried out by Mr. G. A. de Belin, of the Department of Metallurgy.

APPENDIX.—*Notes on the Microstructures.*

BY G. A. DE BELIN (SHEFFIELD).

Specimens Examined (all from the Second Series).—It was considered advisable to record two series of structures. The decision to carry out the "return-twist" experiments was made after the other experimental work had been completed, and it was found that no further rolled bars were available. One billet, however, was left and was then rolled, but not in precisely the same manner as the previous material:

Details of Rolling.

All Bars.
Cogged from 6 to 4 in.,
reheated, cogged to 2 in.

First Bars, then:
Reheated, rolled to 1½ in.,
reheated, rolled to 1 in.

Last Bar, then:
Reheated, rolled to 1⅛ in.

The annealing was the same for all bars, namely, 6 hr. at 650° C., cooling in the furnace. The resultant structure of the first bars was very uniform (Figs. 14 and 15) and the pearlite was completely spheroidised.

Owing, probably, to the higher temperatures of the final rolling, the ferrite-pearlite distribution of the last bar (Fig. 18) was less uniform, and the pearlite remained partly laminated after annealing (Fig. 19).

In all the micrographs, the longitudinal axes of bars and test-pieces are horizontal. The surfaces photographed were obtained by filing a "flat," ¼ in. wide, on the bars, after turning to 0·6 in. in dia. Figs. 16 and 17 show the effect of torsion on the first bars. Both the pearlite grains and ferrite crystals are drawn out, and deep-etching develops strain lines in the ferrite, which appear to be mainly at right angles to the axis of the test-bar.

Fig. 20, single torsion on the last bar, shows the same features as Fig. 16, the visibly greater attenuation of the structure being due to the greater torsion applied. Figs. 18 to 22 typify the effect of the "return-twist." The low-power micrographs (Figs. 18 and 21) indicate that the negative torsion has apparently returned the structure to that of the annealed condition.

Similarly, Fig. 22, when compared with Figs. 19 and 15, shows that, except for the strain lines, the ferrite crystals and pearlite grains have returned to the equi-axed condition.

The ferrite in Fig. 22 has a more confused appearance than that in Fig. 17, which may be due to slip on a fresh series of planes, introduced by the negative torsion. Even so, the more obvious strain lines in Fig. 22 are still mainly at right angles to the longitudinal axis.

This apparent restoration of the structure is at least superficially in line with the restoration of the properties noted above in discussing the effect of reversed torsion and illustrated in Figs. 7, 11 and 13. If the fragmentation or disintegration at the boundaries, illustrated in Fig. 2, is accepted, then Fig. 17 indicates that, following single torsion, such fragmentation forms continuous lines of weakness, arranged at an angle favourable to shear. From Fig. 22 it is seen that the supposed weakened regions become random in distribution with respect to the axis in tension.

A difficulty here is that the return-twist might be expected to increase the fragmentation. A similar anomaly is that the indentation hardness is not increased by the return-twist, in the case examined. The diamond pyramid hardness after a single twist of + 1150° was 218, whereas after a return-twist of ± 1150° the hardness was 227 on a diameter of 0·600 in. (*see* Table V.).

TABLE V.—*Vickers Diamond Pyramid Hardness After Torsion and Tension.*

Mark.	*P*5.	*P*1.	*P*2.	*P*3.	*P*4.	*P*6.
Twist. Degrees on 5 in.	0	180	600	1,150	±1,150	1,750 *
Hardness.						
Initial	129	129	133	134	132	128
After twist { 0·75 in. dia. .	...	175	214	232	230	246–212
After twist { 0·60 in. dia. .	...	169	200	218	...	...
After return twist { 0·75 in. dia. .	...	...	...	...	232	...
After return twist { 0·60 in. dia. .	...	...	...	...	227	...
Neck after tensile fracture. { Max. .	231	223	229	227	252	...
Neck after tensile fracture. { Min. .	217	203	214	217	226	...

* Broke in torsion.

The indentation-hardness results, however, may not give a true picture of the hardness changes due to cold-work, the effect being masked by the pearlite. Work-hardening tests might prove more illuminating.

The number of planes on which slip has occurred in both Fig. 17 and Fig. 22 is probably negligible, compared with the number undisturbed, so that the ductility of the ferrite, when tested to distruction in tension, should be similar in both cases, and more akin to that of the annealed sample than to that of the singly-twisted sample. This view reinforces the suggestion that the weakness produced by severe single torsion is due to the alignment of the weakened regions in the vicinity of the boundaries.

NINTH REPORT ON THE HETEROGENEITY OF STEEL INGOTS.

By a JOINT COMMITTEE of the Iron and Steel Institute and the British Iron and Steel Federation.

This Report is published as Special Report No. 27; it was prepared for presentation at the abandoned Autumn General Meeting of the Iron and Steel Institute which should have been held in Cardiff on September 12, 1939.

SUMMARY.

In this their Ninth Report the Committee on the Heterogeneity of Steel Ingots discuss the theory of rim formation in steel ingots and submit notes on typical practice in the manufacture of rimming-steel ingots in British steelworks.

Considerable attention has been given to rimming steel in previous Reports issued by the Committee. Ingots of this type were included among those examined in the series of researches which were started soon after the formation of the Committee in May, 1924, the object of which was to determine the nature and degree of the heterogeneity commonly found in ingots of different types.

The publication during recent months of several important papers on rimming steel in other countries, notably those by Chipman and his colleagues and by Hultgren and Phragmén,[1] decided the Committee to formulate their ideas in a special Report. The individuals by whom the papers published in the present Report are written are alone responsible for the views expressed, but the Committee are confident that these views will be found of general interest.

Section I. of the Report is introductory in character, and gives an outline of the principal contents of the remaining three Sections.

In Section II., C. A. Edwards, D.Sc., F.R.S., presents "A Review of A. Hultgren and G. Phragmén's Theoretical Discussion of the Process of Solidification of Iron-Carbon-Oxygen Alloys" (*loc. cit.*); this contribution deals with that part of the Swedish authors' paper which relates specifically to the theoretical aspects of the solidification of rimming steel. These authors have attempted to incorporate all the available evidence concerning the influence of varying percentages of carbon and oxygen upon the freezing characteristics of the iron-carbon-oxygen alloys in the form of ternary diagrams. In this way they have been able to give a much

[1] *See* Hayes and Chipman, *American Institute of Mining and Metallurgical Engineers*, 1938, *Technical Publication No.* 988: *Metals Technology*, 1938, vol. 5, Dec.; Hultgren and Phragmén, *Jernkontorets Annaler*, 1938, vol. 122, No. 8, p. 377.

more systematic outline and a far clearer vision of this interesting problem than previously existed.

The present author has endeavoured to bring out the more salient features of Hultgren and Phragmén's work with a view to stimulating discussion on their fundamental conclusions. It is recognised that there are many factors of considerable importance that have not been referred to in the present contribution; nevertheless, it is felt that these can only be profitably discussed after something like agreement has been reached concerning the effects of carbon and oxygen upon the solidification of rimming steel. From the Swedish authors' paper it is possible to follow the changes that occur during the solidification of rimming steel, and to understand how these vary when different percentages of carbon and oxygen are present.

The present author concludes by giving a brief outline of some of the views which he himself has expressed on this subject.

Section III., by T. SWINDEN, D.Met., is entitled "Rimming Steel. Further Studies of the Composition Variation from Outside to Centre." In Section II. of the Committee's Seventh Report the author published a detailed study of the variation in carbon, manganese, sulphur and phosphorus in (*a*) a billet of open-hearth rimming steel containing 0·16% of carbon, and (*b*) an ingot of basic Bessemer steel (Example No. 64), details of which were given in the Sixth Report.

In the present paper an account is given of a further examination of the same basic Bessemer ingot, in which the following supplementary data are now presented: (*a*) Inclusions, a detailed microscopical study; (*b*) Brinell hardness; (*c*) oxygen and nitrogen contents by the vacuum fusion method.

In addition, a detailed study of a basic open-hearth rimming-steel ingot has been made by the examination of cross-sections of a 10½-in. bloom at points corresponding to the top, middle and bottom of the ingot. These have been examined by (*a*) microscopical examination, (*b*) chemical analysis for carbon, manganese, sulphur and phosphorus, and (*c*) vacuum fusion tests for oxygen, hydrogen and nitrogen.

Consideration is then given to the factors influencing segregation of the elements in rimming steel, these results being discussed in the light of contemporary work.

In Section IV., short accounts are given of "Practice in the Manufacture of Rimming Steel" at representative British steel-works using an acid Bessemer, basic Bessemer and basic open-hearth process. The following are the papers included in this Section:

Introduction.

Part 1.— Acid Bessemer Practice.

The Manufacture of Rimming Steel at Workington by the Acid Bessemer Process, by T. SWINDEN, D.Met., and F. B. CAWLEY, M.Met.

Part 2.—Basic Bessemer Practice.
The Manufacture of Rimming Steel by the Basic Bessemer Process at Corby, by W. L. KERLIE, B.Sc.
Part 3.—Basic Open-Hearth Practice.
A.—The Manufacture of Rimming Steel at Templeborough, by N. H. BACON.
B.—The Manufacture of Rimming Steel at the Irlam Works of the Lancashire Steel Corporation, Ltd., by D. BINNIE, Ph.D.
C.—The Manufacture of Rimming Steel at the Normanby Park Steel Works, by J. B. R. BROOKE, A.M.I.C.E.
D.—Notes on the Practice of Making Rimming Steels at the Cardiff Works of Guest Keen Baldwins Iron and Steel Co., Ltd., contributed by the COMPANY.
E.—Rimming Steel Practice at Glengarnock Iron and Steel Works, by J. GIBSON.
F.—Some Notes on the Manufacture of Rimming Steel at Briton Ferry, Using Cold Pig Iron and Scrap in the Basic Open-Hearth Furnace, by J. S. LEWIS.
G.—Rimming Steel from Basic Open-Hearth Furnaces at Bilston, by R. S. ROLFE.
Part 4.—General Survey.
General Survey of the Practical Aspects of Rimming Steel Manufacture, by J. MITCHELL.

The factors necessary for the accurate control of the steelmaking and the rimming action are clearly brought out. It is shown that, whilst there is a general similarity in the methods employed, there are differences as between different works due to variations in the raw material and in the process employed.

In the concluding part of the Section the important practical aspects of rimming-steel manufacture, as brought out by the descriptions given in the earlier parts, are discussed.

ERRATUM.

Referring to the paper in Part 1 of Section IV. on "The Manufacture of Rimming Steel at Workington by the Acid Bessemer Process," by T. Swinden, D.Met., and F. B. Cawley, M.Met., the authors have written since the publication of the Report that, in case any question should arise in the minds of readers regarding the discrepancy between the number of tuyeres shown in the plan in Fig. 35 and the statement that 30 tuyeres are used, they desire to explain that the arrangement including 37 tuyeres was adopted for a time. Subsequent experience did not indicate any advantage from the additional tuyeres, and the original arrangement was reverted

to, in which 30 tuyeres are used, of which 4 are dummies. This arrangment is shown in Fig. A.

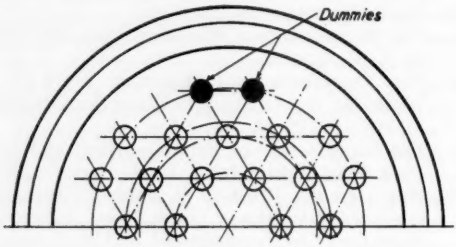


FIG. A.

CORRESPONDENCE.

Section II.

(*Solidification of Iron-Carbon-Oxygen Alloys.*)

Professor A. HULTGREN and Mr. G. PHRAGMÉN (Stockholm, Sweden) wrote that they greatly valued the kindness shown by the Ingot Committee in devoting a Section of the Ninth Report to a discussion of their paper on rimming-steel ingots and wished to thank Principal Edwards for undertaking a presentation and interpretation of that part of their work dealing with the theoretical aspects of the solidification of rimming steel.[1]

The wire models of the Fe–C–O ternary diagram as reproduced in Figs. 4 to 6 undoubtedly helped towards a better understanding of the diagram. They wished, however, to offer the following comments. The line *IK* should decline slightly towards *K*. In Fig. 6 the isothermal lines shown were not tie lines joining two phases in equilibrium, but might be misunderstood as such. In Figs. A and B the writers had tried to indicate part of the Fe–C–O diagram as they conceived it, the former applying to a pressure high enough to suppress the gas reaction and the latter to a pressure of one atmosphere. Tie lines were shown joining the phases in equilibrium.

The author's conception that the gas evolution was the result of a reaction between separated oxygen-rich globules and the carbon in the main liquid involved the assumption that, during the freezing of the outer wall, the adjoining liquid, although saturated with respect to $CO + CO_2$ on the line *MYNZO*, would not give off any gas until, by the continued freezing of δ iron, its composition

[1] Their paper was also presented at the meeting of the American Institute of Mining and Metallurgical Engineers in Detroit in October, 1938, and is now printed in full in the *Transactions* of that Institute.

was brought as far as the monotectic line *BF*. On the other hand, the writers had assumed that under conditions of not too rapid

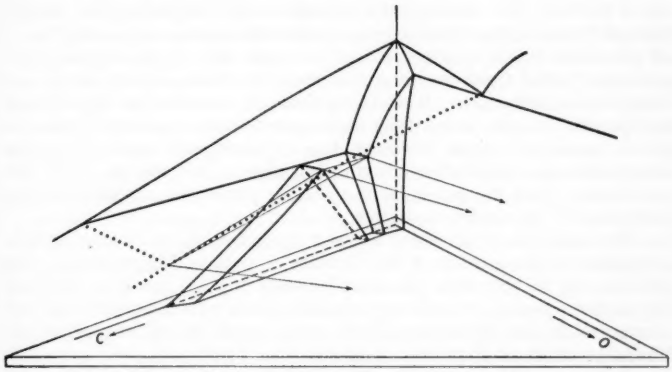


FIG. A.—Iron-Carbon-Oxygen Diagram at a Pressure Sufficient to Suppress the Formation of $CO + CO_2$. The monotectic and peritectic lines are dotted. The single-phase spaces of δ and γ iron are shown and some tie lines indicated. Arrows show tie lines towards FeO.

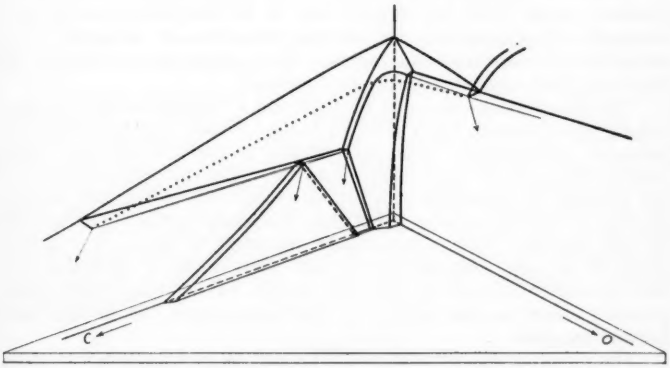


FIG. B.—Iron-Carbon-Oxygen Diagram at Atmospheric Pressure. The intersection line of the δ liquidus surface and the gas equilibrium surface of the liquid steel is dotted. From each of the single-phase spaces of δ and γ iron as shown in Fig. A, part is now cut away by a corresponding gas equilibrium surface. Arrows show tie lines towards $CO + CO_2$.

freezing there would be only slight supersaturation of the liquid in the adjoining layer, *i.e.*, gas would be evolved before any oxide would have an opportunity of separating. In other words, during

the rapid freezing of the outer part of the wall—the skin—there was undoubtedly a considerable amount of supersaturation, sometimes even to the extent that no gas was formed—compare point *P* in Fig. 32 of Section III.—and therefore oxide might separate, but as the rate of freezing was retarded the enrichment of the adjoining layer of the main liquid in (carbon and) oxygen due to the freezing was soon prevented from reaching the stage of oxide separation by gas being evolved from it. It was true that oxide inclusions were found in the wall, but the writers believed those to have separated from the small pools of liquid between the crystals and their branches some distance behind the growing interface. To sum up, they did not believe that the presence of an oxide phase was essential to the evolution of gas during freezing.

The example of an ingot having a good solid outer wall or rim as given by the author at the bottom of p. 9, in their opinion, did not belong to the class of rimming-steel ingots, because the wall would have frozen without any rimming action in the liquid and the composition and structure of the outer wall would not show the characteristics of that of a rimming-steel ingot.

Section III.

(*Composition Variation of Rimming Steel from Outside to Centre.*)

Professor A. HULTGREN and Mr. G. PHRAGMÉN (Stockholm, Sweden) wrote that the author was to be congratulated on his thorough determinations of the distribution of elements and inclusions in rimming-steel ingots. There were several points in this work that might profitably be discussed.

The distribution curves of Figs. 26 and 27 demonstrated clearly, among other things, for a steel of higher carbon content than the balanced composition, that the oxygen content of the rim zone rapidly decreased from the skin inwards. For that reason one was not justified in speaking of a representative figure for the oxygen content of the rim zone as the writers had done in the paper quoted by the author. The inconsistency, referred to on p. 35, in the series of oxygen contents of the rim zone (ingot *F* of Table V.) thus probably arose from the top sample having been taken at a position nearer to the surface of the bloom than the middle and bottom samples.

The peculiar characteristics of the carbon and oxygen variation in successive layers of the rim zone as shown in Fig. 33 were of particular interest to the writers, as those results agreed with their own postulate for a steel of the type mentioned. They hoped that the author would undertake a similar detailed investigation of ingots of lower carbon contents to test their hypothesis in that field. The relative positions of the carbon and oxygen minima in the rim zone should decide the relation of the steel to the balanced composition. The average carbon and oxygen contents of the core as compared

with the original composition of the liquid before freezing might be thought to throw light on that point also if it were not, as they presumed, for the presence of suspended crystals in the interior liquid at the moment when the top was closed.

The small amount of inclusions recorded in the skin (Fig. 18) where the oxygen was high might be explained by considering its fine primary structure and the probability of the smallest inclusions remaining undetected. The gradual decrease of silicate inclusions towards the core (Fig. 18) was a natural consequence of the silicon being consumed by silicate formation in the earlier stages of freezing.

On p. 29 the author stated his view that rimming ceased when the concentration of oxide (or carbon) was inadequate at the given temperature and pressure to allow the reaction to proceed. The writers would rather suggest that in ordinary rimming steels gas evolution and consequent rimming would continue, although more slowly as freezing was retarded, if the top were not closed so as to cause the pressure to rise. If their conception of a balanced composition was correct, the carbon and oxygen contents of the liquid, during the freezing of such a steel, would remain constant and adequate for gas evolution, if the pressure did not rise.

REPLIES TO CORRESPONDENCE.

Section II.

(Solidification of Iron-Carbon-Oxygen Alloys.)

Principal EDWARDS wrote to say how pleased he was to have Professor Hultgren's and Mr. Phragmén's kindly observations with regard to his effort to emphasise the importance of their own work. From the very nature of the work which was under review, and the fact that it was so largely concerned with Professor Hultgren's and Mr. Phragmén's previous paper, it was unnecessary to say much. He (Principal Edwards), however, would like to say how glad he was to have their additional remarks relating to this interesting field of work, towards which they had made such valuable contributions.

Section III.

(Composition Variation of Rimming Steel from Outside to Centre.)

Dr. T. SWINDEN thanked Professor Hultgren and Mr. Phragmén for their comments on this paper and was gratified that it had been possible to make these data available for consideration in the light of the masterly treatise on the subject of rimming-steel ingots by these gentlemen.

The contributors' explanation of the apparent inconsistency in connection with ingot *F* of Table V. was probably correct. It

was clearly desirable that further work on the lines of that contained in this paper should immediately be carried out on an ingot of low carbon content. Fortunately such an ingot was available and this investigation was already well in hand. It certainly would be most interesting to see whether the results fitted into the hypothesis of Professor Hultgren and Mr. Phragmén as did those obtained on the higher-carbon steel.

Referring to the contributors' final paragraph, the author suggested that the difference in the views expressed was not so great as might at first appear. One had to explain not only why the reaction between carbon and oxygen started, and proceeded, but also why it ceased. It was at once agreed that pressure was a very important factor and was referred to by the author in the note on p. 29 of the Report which was quoted. Practical evidence was overwhelming if one considered the technique of cooler-plating which was commonly practised or, further, carried out an examination, as the author had done, of ingots which had had the top deliberately re-opened after normal rimming had ceased. If this was done at the right time, a further certain amount of rimming would occur. Nevertheless, the author still felt that in a general conception of the problem, the concentration of carbon and oxygen must be a primary factor in controlling the commencement and extent to which true rimming would take place. The point was of academic rather than of practical interest, in that it was clearly impossible to avoid a rise in pressure while the ingot was freezing.

The author would take this opportunity of repeating his high appreciation of the work of Professor Hultgren and Mr. Phragmén in focusing attention on this very interesting type of steel.

OBITUARY.

Professor HENRY LOUIS died at his home at Osborne Terrace, Jesmond, Newcastle-on-Tyne, on February 22, 1939; he was in his eighty-fourth year. The son of a lace merchant in London, he was born on December 7, 1855; he received his education in Bavaria and at the City of London School, where he was a scholar and medallist. He also gained the William Tike Scholarship and a series of other awards, including the Mortimer Exhibition for Science, and the Royal Exhibition at the Royal School of Mines, whence he emerged with the De la Beche Medal—the highest award then given—and the Associateship in Mining and Metallurgy. He first took a post as chemist with Dr. John Percy, and a few months later Sir William Siemens offered him the position of chemist to the Steel Company of Canada, Nova Scotia; he remained there for three years, and then made a tour of the iron and steel districts of the United States of America before returning to England, where he carried out some experiments for Sir William Siemens on open-hearth steelmaking.

For much of his time, Professor Louis was occupied with mines and mining. He was assistant manager and assayer to a gold mine in Ecuador; in 1885 he went to the Transvaal to test and prove seams in gold mines, and he also visited gold mines in California. With Mr. H. A. Becher he founded the firm of Becher, Louis & Co. in Singapore in 1890, and for four years he was engineer, manager and consultant for various mines in the Malay Peninsula, Siam and Borneo; he also managed an iron-ore mine in Spain.

From 1896 to 1923 Professor Louis was Professor of Mining and William Cochrane Lecturer on Metallurgy at Armstrong College in the University of Durham. He was the first to introduce elementary metallurgy and metallography as a part of the curriculum of naval architecture and engineering—an example soon followed by other universities.

On resigning his position at the University, Professor Louis turned more to the scientific side of the iron, steel and mining industries, and produced a number of publications; among these were "The Handbook of Gold Mining," a revised translation of Schnabel's "Text-Book on Metallurgy," "The Dressing of Minerals," "The Metallurgy of Tin," "Electricity in Mining," "Shaft-Sinking in Practical Coal-Mining," and "The Production of Tin." During his career he had communicated many technical articles to various journals, and he submitted four papers to the Iron and Steel Institute: "The Chemistry of Puddling" (1879); "An Improved Dipping Needle" (1899); "The Manufacture of

Pig Iron from Briquettes at Herräng " (1904); and " Ancient Lease of a Forge " (1930).

Professor Louis was connected with many technical societies, both British and foreign. He had been President of the Institution of Mining Engineers and of the Society of Chemical Industry, was a Fellow of the Imperial College of Science and Technology, and was a member of the Institute of Metals. He joined the Iron and Steel Institute in 1881, became a Member of Council in 1918, was elected a Vice-President in 1925, and was President from 1929 to 1931; he was awarded the Bessemer Gold Medal in 1932. He also held seats on numerous educational boards, and was appointed by the Minister for Mines in 1930 as one of the two commissioners to enquire into the practicability of gold-mining in Merionethshire. In 1902 he had been sent as a Special Commissioner for the Colonial Office to investigate the Pitch Lake in Trinidad.

ALEXANDRE DREUX, Honorary President of the Société des Aciéries de Longwy, of the Comité des Forges de France and of the Chamber of Commerce at Nancy, died on April 15, 1939, at his home, the Château de Mont-Saint-Martin. Born at Villaines-la-Carelle (Sarthe) in 1853, Monsieur Dreux went to Eastern France about 1877, and undertook the direction of the Comptoir Métallurgique de Longwy. Later, in 1888, he joined the Aciéries de Longwy as Managing Director; he took part in researches on the iron ores and coal in Lorraine, and brought a period of great prosperity to the Aciéries de Longwy, which firm had known difficult times.

From 1908 onwards he was ably assisted by his son Edouard, who had studied in foreign iron and steel works; his help was invaluable during that period of prosperity, and still more so after the trying times which followed the Great War, when everything in the works had to be started afresh, with the result that by 1923 the plant had regained its pre-war capacity. Then his son died suddenly in Paris, and Monsieur Dreux consented to resume the reins, first as Vice-President and then President until recent years.

Monsieur Dreux had a long association with the Iron and Steel Institute. Elected to Membership in 1889, he became a Member of Council in 1924 and an Hon. Vice-President in 1932.

Monsieur Dreux was a great metallurgist and was one of the first to introduce the basic Bessemer process into France. By his death the French steel industry and Lorraine have lost an outstanding personality.

CHARLES MICHAEL SCHWAB died in New York on September 18, 1939, at the age of seventy-seven. Born on February 18, 1862, at Williamsburg, Blair County, Pennsylvania, he received his early education at the local school at Loretto, whither his family had moved, and at St. Francis College. His first post was that of assistant in a grocer's shop at Braddock, Pa., which was fre-

quented by work-people from the Edgar Thomson Steelworks of Messrs. Carnegie Brothers & Co.; here he came under the notice of Captain W. R. Jones, superintendent of the works, who, being impressed by the young man's energy and intelligence, gave him a job in the works of driving stakes at a dollar a day. Mr. Schwab's mechanical and organising abilities and his capacity for managing men soon asserted themselves, and on the death of Captain Jones he succeeded to the superintendency. In 1892 he was also given the similar position in the Homestead Works of the Carnegie Steel Company; four years later he became a member of the board of managers of the concern, and in the following year was elected President in succession to Carnegie.

About this time it became realised that for further economic development a fusion of interests among the larger steel companies was necessary. Largely through Mr. Schwab's ability and energy an amalgamation was effected, and in 1901 the United States Steel Corporation came into being, with Mr. Schwab as President. In 1903 he resigned from this position, and, while retaining large personal interests in the Corporation and its subsidiaries, he bought a steelworks in Bethlehem, Pa., into the development of which he threw all his energies. This concern later was included in the ill-fated United States Shipbuilding Company; the successor to this shipbuilding combination was called the Bethlehem Steel Corporation, and Mr. Schwab was made its President.

During the Great War of 1914–1918, Mr. Schwab was of incalculable help to Great Britain and her allies. After the outbreak of the war he offered to place the whole resources of his works at the British Government's disposal. He built submarines in record time and supplied vast quantities of munitions. When the United States entered the war the submarine campaign was at its height and the need for more and more ships was urgent. At President Wilson's pressing invitation he became Director-General of the Emergency Fleet Corporation, so becoming responsible for the execution of the programme of construction adopted by the Shipping Board; he resigned this position in December, 1918, when hostilities had ceased.

Mr. Schwab received many honours during the course of his career. He was made an Officer of the Legion of Honour by the French Government for his services during the war. In 1928 the Council of the Iron and Steel Institute awarded him the Bessemer Gold Medal, and in 1932 he received the Melchett Gold Medal from the Institute of Fuel.

Mr. Schwab had for long been a member of the American Iron and Steel Institute. In 1927 he was elected President in succession to the late Mr. E. H. Gary; he occupied this position for five years and then became Chairman of the Board of Directors of the Institute, which position he resigned in 1934. His association with the (British) Iron and Steel Institute had also been long, for he became

a Member as long ago as 1895; in 1926 he was elected an Honorary Vice-President.

With Mr. Schwab's death the iron and steel industry of the United States of America loses one of its most outstanding personalities.

Mr. E. J. BARNES died on September 19, 1939. He was educated at Sheffield Grammar School and later at the Technical School, St. George's Square, Sheffield. He first joined the staff of Messrs. Hadfields, Ltd., as a junior assistant in the chemical laboratory of the Hecla Works, and later he was transferred to the steelmaking department as under-manager. In 1920 he joined the Barrow Hematite Iron & Steel Co., Ltd., in a managerial capacity, and later he took a similar position in South Staffordshire. In 1925 Mr. Barnes returned to Sheffield to become manager of the steel-melting plant at Messrs. Hadfields, Ltd., which position he held until his death; he was appointed a local director of the firm in 1929.

During his long membership of the Iron and Steel Institute, Mr. Barnes contributed several papers to the Institute. His first paper, written in collaboration with Professor Andrew McWilliam, on "A Heat-Treatment Study of Bessemer Steels," was published in 1909; in the following years these co-authors presented four further papers, on "Some Physical Properties of 2% Chromium Steels" (1910), "Influence of 0·2% Vanadium on Steels of Varying Carbon Content" (1911), "Some Properties of Heat-Treated 3% Nickel Steels" (1911), and "Brinell Hardness and Tenacity Factors of a Series of Heat-Treated Special Steels" (1915). In 1938, together with Dr. R. J. Sarjant, he contributed a paper on "Some Experiences in the Design and Control of Open-Hearth Furnaces" to the "Symposium on Steelmaking" organised by the Iron and Steel Institute and held in conjunction with the May Meeting of that year.

Mr. Barnes was elected a Member of the Iron and Steel Institute in 1905.

Professor HERBERT MELVILLE BOYLSTON died at his summer home at Edgartown, Mass., U.S.A., on July 28, 1939, at the age of fifty-eight. Born in Brooklyn, N.Y., Mr. Boylston attended Harvard University; he graduated in 1903 and took a degree in metallurgy in 1905. His first post was that of private technical assistant to Dr. H. M. Howe; among other duties, he assisted in the revision of Dr. Howe's book "Iron, Steel and Other Alloys." In 1906 he became an instructor at Harvard University and taught metallography and metallurgy under the late Professor Sauveur. He also assisted the professor in consulting practice and in the development and sale of metallographic equipment; they formed a partnership, of which Professor Boylston was the managing partner. In 1920 Professor Boylston joined the Case School of Applied Science,

Cleveland, where he was Professor of Metallurgy and Head of the Department of Metallurgical Engineering until his retirement in 1938 owing to ill-health.

Professor Boylston was the author of a book entitled "Introduction to the Study of Metallurgy," which has been adopted as a standard text-book by a number of American colleges. He also wrote many papers on the metallography of iron and steel for the American Institute of Mining and Metallurgical Engineers and the American Society for Metals. In 1916 his paper on "Investigation of the Relative Merits of Various Agents for the Deoxidation of Steel," describing a research carried out with the aid of a grant from the Andrew Carnegie Research Fund, was published by the Iron and Steel Institute in the *Carnegie Scholarship Memoirs*. In addition to serving for ten years as the first Chairman of the Publication Committee of the American Society for Metals, Professor Boylston played an active part in the work of the American Institute of Mining and Metallurgical Engineers, the American Society for Testing Materials, the American Welding Society and other technical bodies.

Professor Boylston joined the Iron and Steel Institute in 1907.

HORACE BREARLEY died at his home, 18 Thornsett Road, Sheffield, on May 18, 1939; he was sixty years of age. Mr. Brearley's father, Mr. W. H. Brearley, had collaborated with the late Mr. W. T. Beesley in the establishment of W. T. Beesley & Co., Ltd., of Universal Steel Works, Sheffield, and Mr. Horace Brearley joined the firm; he served the company for thirty years, and became a director. Then he went to Messrs. J. J. Habershon & Sons, Ltd., steel rollers, of Holmes Mills, Rotherham, as manager of their cold-rolling department, and in time became a director of this company also.

Mr. Brearley joined the Iron and Steel Institute in 1933.

Professor WITOLD BRONIEWSKI, of Warsaw, Poland, died on February 13, 1939. Descended from the ancient Polish family of Firley, he was born at Pskow on October 15, 1880. After completing his studies at the University at Cracow, he went to Nancy (France) to work in the laboratory of Professor Guntz, after which he went to Paris, where, in the laboratory and under the direction of his teacher, Henry Le Chatelier, he turned his attention definitely towards metallography and prepared his notable thesis on the electrical properties of alloys. He gained the degree of Doctor of Science in 1911, and, after a short period at the Polytechnic School at Lwow, he commenced to give lectures in metallography at the Sorbonne (Paris) and worked for some time in the laboratory of his compatriot, Madame Curie.

During the Great War he first worked for a while in French war industries, but on their formation he joined up with the Polish military formations of General Haller and fought with him, in 1919,

on the eastern frontier of his country. At this time he was nominated professor at the Polytechnic School at Warsaw; however, he refused the appointment, and during the war of 1920 fought as a private soldier—this shows clearly his intense devotion to his country and his inflexible character.

In 1926 he became Minister of Public Works, but he gave up this position later to return to his studies and his laboratory which he had organised at the Institute of Metallurgy of the Polytechnic School of Warsaw.

Professor Broniewski was the author of two text-books : " Introduction to the Study of Alloys " and " Practical Work in Metallography." He wrote numerous papers, many of which appeared in French publications.

He was a Laureate of the French Académie des Sciences and was awarded a gold medal by Nancy University at the time of the Congress on Industrial Chemistry held in September, 1938. From 1928 till 1937 he carried out the duties of Secretary-General of the Academy of Technical Sciences at Warsaw.

Professor Broniewski joined the Iron and Steel Institute in 1937.

JOHN BRADFORD CORRIE, Chairman of Foundry Equipment, Ltd., Leighton Buzzard, died on March 3, 1939. He was well known in many parts of the world, because his firm, J. B. Corrie & Co., sold the products of British engineering and iron and steel companies in India, South America and France. At one time his business was principally concerned with Sheffield-made railway material, machine tools from Manchester, hydro-electric schemes and electric furnaces. After the Great War business conditions altered and exports became more difficult, so the importation of machinery was started. For a while Mr. Corrie's firm acted as agents for the British Empire for Alfred Baillot et Cie., of France, but again conditions changed when the British fiscal system altered from free trade to protection. In conjunction with Mr. Baillot, Mr. A. S. Beech and his son, Mr. A. G. Corrie, Mr. Corrie set up a works at Leighton Buzzard for the manufacture of a complete range of foundry plant.

Mr. Corrie became a Member of the Iron and Steel Institute in 1907.

CHARLES RICHARD CRANE died in February, 1939, in Palm Springs, Cal., U.S.A.; he was eighty years of age. The son of the founder of the Crane Co., Mr. Crane received his education in Chicago public schools; he then travelled extensively, and later joined the Crane organisation at the end of the last century. In 1912 he became President of the company, and retired in 1914. He served on President Wilson's special diplomatic commission to Russia in 1917, and as America's commissioner on mandates in Turkey in 1919. In 1920, President Wilson appointed him Minister in China, where he held this post for two years.

Mr. Crane joined the Iron and Steel Institute in 1922.

WYBERT FIRTH, of Selby Lodge, Consett, Co. Durham, died on May 17, 1939, at the age of fifty-eight. He was born at Rotherham and received his education at Rotherham Grammar School and Sheffield University; he then served his time as an engineer in the Midlands. He next stayed for two years in Pittsburgh, Pennsylvania, where he gained further experience, after which he took a post at Wellington, Shropshire, where he remained for five years. After serving a similar period as an engineer at Ebbw Vale, Monmouthshire, he joined the Consett Iron Co., Ltd., as chief engineer in 1917; three years later he became works manager of the firm, and the big reconstruction scheme at the works in 1926 was carried out under his direction.

Mr. Firth joined the Iron and Steel Institute in 1918.

JOSEPH ERNST FLETCHER died at Dudley on November 30, 1939; he was seventy-two years of age. He was born at Chesterfield and received his education at Sheffield; he served his apprenticeship in the works of the Clay Cross Company and became foundry manager and later works manager in the steelworks of Thos. Firth and Sons and Cammell, Laird and Co. In 1905 he was appointed chief engineer to N. Hingley and Sons, Netherton, to which firm, in later years, he became consulting metallurgical engineer.

Mr. Fletcher was an original member of the Council of the British Cast Iron Research Association, and he later became consultant to the Association, particularly on melting practice. He designed and patented, jointly with the British Cast Iron Research Association, the type of cupola furnace which became known as the balanced blast cupola, over two hundred installations of which have been made in this country and abroad.

Mr. Fletcher was the author of numerous technical papers, four of which have been published in the *Journal of the Iron and Steel Institute*: "Practice in the Manufacture of Malleable Cast Iron" (1917); "Cooling of Steel in Ingot and other Forms" (1918); "Blast-Furnace and Cupola Slags: Their Composition and Graphic Methods for Determining their Constitution" (1921); and "Some Characteristics of Moulding Sands and their Graphical Representation" (1923). In connection with his scientific activities and his business he travelled extensively on the Continent and in the United States of America.

Mr. Fletcher was a Past-President of the Staffordshire Iron and Steel Institute and a member of the Institution of Mechanical Engineers, by which body he was, in 1926, awarded the Bernard T. Hall Prize. He was an old member of the Iron and Steel Institute, having been elected in 1902.

Major ROBERT BELL GLOVER died in October, 1939, at the age of sixty-eight. He was managing director of Glover Bros. (Mossley), Ltd., wire-rope manufacturers, and was associated with many other

industrial concerns in England. He was elected a Member of the Iron and Steel Institute in 1903.

JAMES H. GRAY, of Berkeley, California, U.S.A., died on January 13, 1939. He started his career as a metallurgist with the Illinois Steel Co.; later he became assistant to the late Mr. W. R. Walker at New York, when the latter became Vice-President of the United States Steel Corporation when that concern was being organised. He was concerned with the investigation of new processes, and came to Europe to report on the electric furnace patented in France by Dr. Paul Heroult. The latter accompanied him to the United States and is credited with having set up the first electric furnace in that country. Mr. Gray took charge of the Heroult furnace department of the Steel Corporation and became a leading figure in the electric steel side of the industry.

In 1924 Mr. Gray resigned the chairmanship of the open-hearth steel committee of the Steel Corporation and other connections, and moved to Nice, France, but a few years ago he returned to the United States.

Mr. Gray was elected a Member of the Iron and Steel Institute in 1907.

FRED C. A. H. LANTSBERRY, President and director of Messrs. William Jessop & Sons, Inc., an associated company of Messrs. William Jessop & Sons, Ltd., steel manufacturers, Sheffield, died at Scarsdale, New York, U.S.A., at the age of fifty-five. He was born and educated in Manchester, and started his career in the electrical industry in England. He went to the National Physical Laboratory at Teddington, and later joined the Birmingham Small Arms Company in Birmingham, where he was in charge of the laboratory. In 1920 he went to Sheffield to join Messrs. William Jessop & Sons, Ltd., an associated company of the B.S.A. Company. He started as works manager and later became Managing Director, which post he held until 1928. In that year he went to the United States of America to take charge of the American and Canadian interests of the firm.

Mr. Lantsberry, who was also a member of the Institute of Metals, joined the Iron and Steel Institute in 1908.

KENNETH D. MACKENZIE died in a Glasgow nursing home on May 8, 1939. As a young man he went to Glasgow and for a time was secretary of Arrol's Bridge and Roof Co. in Springburn. Later he entered the service of Messrs. Frederick Braby & Co., Ltd., steel sheet makers and structural engineers, with which firm he was associated for over forty years; he was a director of the company for twenty-five years, and for a similar period he was general manager of the firm's Eclipse Works in Springburn and its other branches at Falkirk and Motherwell.

In the steel industry of the country his knowledge and experience were recognised; he was elected a member of the British Iron and Steel Federation, and represented his firm at the Sheet Makers' Conference, an important section of the Federation.

Mr. Mackenzie had been a Member of the Iron and Steel Institute since 1920.

EMILE MOND, a nephew of the late Dr. Ludwig Mond, died on December 30, 1938, at the age of seventy-three. He received his early education at the Collège de Sainte Barbe, Paris, and the Lycée Condorcet; at the Polytechnicum, Zürich, where he specialised in chemistry, he took his diploma. He commenced his technical career in England with Brunner, Mond & Co., but soon left the firm to found the West Indies Chemical Works in Jamaica with Dr. Emile Bucher, of Geneva, his friend and a former fellow-student. Later, he returned to England and became technical assistant to his uncle, specialising in patent work. In course of time he joined the board of Brunner, Mond & Co., Ltd., and the Mond Nickel Co., Ltd.; he became vice-chairman of the latter company. He also held the chairmanships of the South Staffordshire Mond Gas Co., the Power Gas Corporation, Ltd., and Ashmore, Benson, Pease & Co., Ltd. He always retained his early-acquired love of chemistry and took an interest in many branches of modern research; he became honorary treasurer of the Faraday Society in 1930 and of the Chemical Society in 1931. The French Government conferred on him the distinction of Officier de la Légion d'Honneur and the King of the Belgians made him an Officier de l'Ordre de Leopold in recognition of his important work in connection with the Lycées de Londres founded in 1915 to provide educational facilities for French and Belgian refugee children during the Great War. Later he founded the Francis Mond professorship of aeronautical engineering at Cambridge in memory of his son who was killed while flying in France in 1918.

Mr. Mond joined the Iron and Steel Institute in 1907.

Colonel JOSEPH GEORGE NEEDHAM, D.S.O., O.B.E., T.D., D.L., of Manchester, died on September 11, 1939; he was sixty-three years of age.

Colonel Needham was a well-known figure on the Manchester Royal Exchange and on the Birmingham Exchange; he was a Governing Director of Messrs. John Needham & Sons (Manchester), Ltd., iron and steel merchants.

Outside business affairs Colonel Needham's main interest lay with the Territorial Army. As a young man he served as a Volunteer, first in the Mounted Infantry and later in the 5th battalion of the Lancashire Fusiliers. Later, when the Territorial Army was formed, he transferred to the Royal Army Service Corps. When war broke out in 1914 he was in command of the 42nd (East Lancs.) Divisional Train, and in September of that year he went with the

Division (the first Territorial Division to go overseas) to Egypt. For the rest of the war he served in Egypt and Palestine. He was mentioned four times in despatches, and was decorated with the D.S.O. and the O.B.E. At the time of his death he was Honorary Colonel of the 42nd (East Lancs.) Royal Army Service Corps (T.A.).

After the war, Colonel Needham did a great deal to promote the success and well-being of the Territorial Army in the Manchester area. He was a member of the East Lancashire Territorial Army and Air Force Association, and served on numerous sub-committees. He was also keenly interested in the care of ex-servicemen; he was a member of the Committee of the Barrowmore Tuberculosis Colony (a resident colony of ex-servicemen under the care of the British Red Cross Society), and also an active President of the Didsbury branch of the British Legion and of the 42nd (East Lancs.) Division Old Members' Association.

Colonel Needham, who was also a member of the Institute of Metals, had long been associated with the Iron and Steel Institute, for he took up membership in 1908.

Ernst Odelberg died on February 2, 1939, at the age of seventy-eight. Born at Västerås in Sweden, he had, at the early age of fourteen, owing to the death of his parents, to fend for himself by undertaking clerical work for about six years. He was an engineering apprentice in Stockholm from 1882 to 1883 and a master smith at Larsbo in 1884; he also studied at the Filipstad School of Mining. After being engineer and outside work's manager at Lesjöfors from 1886 to 1895, he became manager of Strömsnäs Jernwerks Aktiebolag, Degerfors, with which company he remained almost until his death. He was on the board of directors of this company for forty years and its Chairman for the greater part of this time.

He was also interested in a number of mining companies, and his efforts to improve the methods of ore preparation led to his installing the first sintering plant in Sweden at Degerfors in 1914. The question of fuel for blast-furnaces was one in which he took an active interest, and about 1910, after experimental work in collaboration with Sohlman, he introduced a new type of charcoal blast-furnace; soon afterwards he was trying out coke as a fuel, and his success with this led to the conversion of the Degerfors blast-furnaces to work on coke instead of charcoal.

About this time (1910) Jernkontoret appointed him chairman of a committee charged with examining the practical possibilities of using an electric blast-furnace for the production of pig iron, and from 1912 to 1929 he was Chairman of Aktiebolaget Trollhättans Elektriska Masugn which exploited the process.

As was to be expected, the advice of a man with such a practical knowledge of the metallurgical industries was constantly sought and he was therefore on the board of directors of several companies. Mr. Odelberg became a Jernkontor delegate in 1925 and was Chair-

man of this association from 1932 to 1936. In recognition of his great services to the mining industry of Sweden he received the Jernkontoret Gold Medal in 1925.

Although he had so many industrial interests, he kept in mind the welfare of his employees and the community in general, evidence of this being seen in the establishment of a pension scheme at his works, and in his participation in local administration.

Mr. Odelberg was elected a Member of the Iron and Steel Institute in 1905.

FRANCIS ROSSER PHILLIPS died at his home at Pontardawe on July 2, 1939; he was seventy-one years of age. He was formerly manager of the Bryn Tinplate Works, which merged with Richard Thomas & Co., Ltd., some three years ago. He was an important figure in the tinplate trade; he was Chairman of the joint industrial council on the employers' side, and served on the joint conciliation board. He was one of the representatives on the International Cartel.

Mr. Phillips joined the Iron and Steel Institute in 1910.

Professor ALBERT SAUVEUR, Emeritus Professor of Metallurgy and Metallography at Harvard University, died at his home in Cambridge, Massachusetts, U.S.A., on January 26, 1939, at the age of seventy-four. Born at Louvain, Belgium, in 1865, he received his education at schools in Brussels and Liége and at Massachusetts Institute of Technology. He specialised in mining and metallurgy. In 1889 he was appointed to the Pennsylvania Steel Co., and in 1890 he joined the research laboratory of the Illinois Steel Co. In 1895 he started teaching at the Massachusetts Institute of Technology and the Metallurgical Department of Harvard University, where he served as instructor and assistant professor from 1899 to 1905; in that year he was elected to the Gordon McKay Chair of Metallurgy and Metallography at Harvard University, which position he held until 1935, when he retired as Emeritus Professor. From 1917 to 1919 he was Director of the Division of Metallurgy of the Technical Section of the Air Service, A.E.F.

Professor Sauveur contributed many articles to the technical press, and was founder and editor of *The Metallographist* from 1898 to 1903 and of *The Iron and Steel Magazine* from 1903 to 1906. In 1921 he published his text-book on "The Metallography and Heat Treatment of Iron and Steel." To the Iron and Steel Institute he submitted six papers: "Further Notes on the Hardening of Steel" (1896, jointly with Professor H. M. Howe); "The Relation between the Structure of Steel and its Thermal and Mechanical Treatment" (1899); "The Constitution of Iron-Carbon Alloys" (1906); "The Allotropic Transformations of Iron" (1913); "Dendritic Segregation in Iron-Carbon Alloys" (1925, jointly with V. N. Krivobok);

and " The Influence of Strain and of Heat on the Hardness of Iron and Steel " (1925, jointly with D. C. Lee).

Professor Sauveur received honours from many countries. He was an Officer of the Order of Leopold of Belgium, a Chevalier of the Legion of Honour of France and an Officer of the Academy of France. In 1913 he received the Elliott-Cresson Gold Medal of the Franklin Institute, and in 1924 was awarded the Bessemer Gold Medal by the Iron and Steel Institue. He was the first to receive the Albert Sauveur Achievement Medal established in his honour by the American Society for Metals, and was awarded the degree of Doctor of Science by the Case School of Applied Science (1921), Grenoble University (1924), the University of San Marcas, Peru (1925), and Harvard University (1926), while the degree of Doctor of Engineering was conferred on him by Lehigh University (1926). He was the Henry M. Howe Lecturer before the American Institute of Mining and Metallurgical Engineers in 1924; President of the John Fritz Medal Board of Awards in 1916–1917; Vice-President of the American Institute of Mining and Metallurgical Engineers (1910–1912); a Fellow of the Academy of Arts and Sciences; a member of the American Philosophical Society, the American Iron and Steel Institute, the Institute of Metals, the American Society for Testing Materials; an honorary member of the American Society for Steel Treating, the Society of Engineers of Liége School of Mines; and a corresponding member of the French Society for the Encouragement of National Industry. He was elected a Member of the Iron and Steel Institute in 1904.

Frank Moreton Thomas died at his home, Haywood Abbey, near Stafford, on January 21, 1939, at the age of sixty-four. A native of Staffordshire, he was a well-known engineer and metallurgist, and, until his retirement about six years ago, was a principal officer of the Port of London Authority. Mr. Thomas helped to found the Birmingham Metallurgical Society, and in 1908 he was elected a Fellow of the Chemical Society. He wrote numerous technical articles for English and foreign journals. He became a Member of the Iron and Steel Institute in 1905.

Dr. Carl Reimar Eugen Wohrman, of Attleboro, Mass., U.S.A., died on August 30, 1938. Born at Saarema, Esthonia, on September 16, 1897, he received his scientific training at Harvard University; he obtained the degrees of B.S. in metallurgy in 1924, Min. Eng. in 1925, Met. Eng. in 1926 and Sc.D. in metallurgy in 1927. He held several scholarships at that University.

He first held the post of private assistant in mathematics and mechanics, but later became consulting research engineer to the American Rolling Mill Company in 1926; he left that firm in order to study at the Optical Institute, Jena, Germany, during 1927 and 1928 under a National Research Fellowship. He next held

a post on the research staff of the Bell Telephone Laboratories, New York, from September, 1928, until July, 1929, and was operating manager of the Alpine West Electric Company, Switzerland, from then until November, 1930, when he joined the General Plate Company, Attleboro, as research director, a position which he held at the time of his death.

Dr. Wohrman was the author of several technical papers, including papers on iron-manganese alloys and inclusions in iron. He received the Henry Marion Howe Medal in 1929.

He was a member of the American Institute of Mining and Metallurgical Engineers, the American Society for Metals, the American Society for Testing Materials and the Institute of Metals; he joined the Iron and Steel Institute in 1926.

Dr. Richard Vernon Wheeler, F.G.S., F.I.C., F.C.S., Professor of Fuel Technology at the University of Sheffield, and Director of the Safety in Mines Research Stations at Sheffield and Buxton, died at his home, Stumperlowe Mansions, Sheffield, on October 28, 1939, at the age of fifty-six. He was the son of the late R. J. Wheeler, Chief Inspector of Machinery for the Royal Navy, and was educated at Plymouth College and at Owens College (later the University of Manchester), where he gained a Dalton Scholarship and was elected Fellow of the University. After three years of post-graduate research on the combustion of hydrocarbons and on surface combustion in collaboration with the late Professor W. A. Bone, Dr. Wheeler became fuel chemist and later plant gas manager to Messrs. Monks Hall & Co., Warrington. With his next appointment as chemist to the British Coal Dust Experiments Committee of the Mining Association of Great Britain he commenced what proved to be a long and fruitful period of research on the causes and methods of preventing explosions in coal mines. He became chief chemist to the Explosions in Mines Committee of the Home Office Experimental Station at Eskmeals, in Cumberland, and in that capacity continued the researches into the prevention of coal-dust explosions by the application of stone dust which had been inaugurated by Sir William Garforth; to this study he devoted over twenty years to such good purpose that his work gained him international fame, and, early in 1938, he received in conjunction with Dr.-Ing.e.h. Carl Beyling (director of the Westphalian Safety in Mines Experimental Station) the Gold Medal of the Institution of Mining Engineers "in recognition of his eminent services in the application of scientific knowledge and research to industry, with special reference to safety and health in coal-mining, and to the utilisation of coal." In 1921 he was appointed to be the first Professor of Fuel Technology in Sheffield University, in which capacity he directed researches into the second of the two problems which commanded his interest, namely, the constitution of coal. His earlier investigations of this subject had culminated in the publication, in 1918, in collaboration

with Dr. Marie C. Stopes, of the classic work " The Constitution of Coal." At Sheffield University Dr. Wheeler carried out and supervised many research programmes into the more efficient utilisation of fuel in the principal local industries of Sheffield, and with Dr. R. A. Mott was joint author of " Coke for Blast Furnaces," published in 1930. He was frequently consulted by many government departments and industrial organisations in regard to the application of scientific knowledge to industry. In addition to serving on the important committees already mentioned, he was a member of many societies, among which were the Iron and Steel Institute, the Institution of Mining Engineers, the Institution of Petroleum Technologists, the Institute of Fuel, the American Institute of Mining and Metallurgical Engineers and the Midland Institute of Mining Engineers. He was President of the last-named society from 1929 to 1932. His numerous contributions to the technical literature on fuel covered a long period of years, during which he, in collaboration with other authors, presented the following papers before the Iron and Steel Institute: " The Chemical Control of the Basic Open-Hearth Process ", " An Investigation on the Use of Steam in Gas-Producer Practice "; " Further Experiments upon Gas-Producer Practice "; " Coke Consumption in Blast-Furnace Practice: The Effect of Removal of Breeze "; " A Coke-Fired Reheating Furnace "; and " Improving the Coking Performance of Weakly-Caking Coals." In addition to the gold medal previously mentioned, he was awarded the Melchett Medal of the Institute of Fuel in 1938 and delivered the Melchett Lecture to that institute in the same year.

With the passing of Dr. Wheeler, not only Great Britain, but also the other industrial countries of the world lose the services of an indefatigable research worker who will always be remembered for his contributions to the knowledge of coal and, more particularly, for having raised research on safety in mines to an international plane. He was elected a Member of the Iron and Steel Institute in 1907.

SECTION II.

A SURVEY OF LITERATURE ON THE MANUFACTURE AND PROPERTIES OF IRON AND STEEL, AND KINDRED SUBJECTS.

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The Editor has been assisted in the preparation of this Survey by R. Elsdon, Librarian of the Institute.

REFRACTORY MATERIALS

Chrome Ores as Used in the Refractories Industry. T. R. Lynam and W. J. Rees. (Transactions of the British Ceramic Society, 1939, vol. 38, Mar., pp. 211–225). The authors make a detailed examination of five different chrome ores used in the refractories industry and they find that a crushed high grade ore (*i.e.*, one low in serpentine) has a low mechanical strength at high temperatures due to the lack of bond. Work is proceeding with the object of introducing the necessary bond to a high grade ore without destroying its neutrality. A brick made from such ore would be valuable for use in the neutral course in steel furnaces.

Effect of Sodium Aluminate on the Thermal Expansion of Refractory Clay Bodies. W. R. Morgan. (Journal of the American Ceramic Society, 1939, vol. 22, Mar., pp. 88–90). The author studied the effect of the addition of sodium aluminate on the expansion of the cristobalite in highly siliceous Florida clay-flint mixtures and on Missouri semi-flint clay. He found that additions of 2% of sodium aluminate appreciably reduced this expansion in the Florida clay-flint mixtures, but when added to Missouri semi-flint clay it promoted the formation of cristobalite and increased the expansion slightly after a single firing. After a second firing, however, its effect was to promote the formation of glass and to decrease the expansion.

Spalling of Silica Brick during Heating and Cooling of Furnaces. J. M. McKinley and S. M. Phelps. (Journal of the American Ceramic Society, 1939, vol. 22, Mar., pp. 83–88). The authors describe how they investigated the causes of the surface cracking and spalling of silica bricks which frequently occur in the linings of open-hearth furnaces. In the first group of tests samples of brickwork were slowly heated to temperatures of 400°, 600° and 800° C. and cooled rapidly, in some cases by an air blast, and in others with a blast of air and water mist. In the second group of tests the samples of brickwork were heated to 815° C. in time periods ranging from 30 min. to 4½ hr. From their observations the authors conclude that this method of testing was capable of producing exactly the same type of spalling observed in the roofs of open-hearth furnaces, and that rapid cooling with an air blast and rapid heating are very conducive to this kind of failure.

Failure of Coke-Oven Walls by Reaction with Coal Ash. W. C. Rueckel. (American Ceramic Society, Mar., 1937 : Fuel in Science and Practice, 1939, vol. 18, Feb., pp. 36–42). The author investigated the causes of the erosion of the lower part of the walls of coke-ovens in which a coking coal containing 36–40% of volatile

matter was used. To produce a satisfactory coke with this coal the ovens were worked at an unusually high temperature, that of the walls being 1230–1250° C. a few minutes after pushing out the coke. The author arrived at the following conclusions: (1) Disintegration is caused by the action of the iron in the ash on the silica brick at high temperatures; (2) disintegration is localised along the bottom half of the oven wall by the high rate of combustion; (3) although the iron penetrates half way through the bricks, the formation of pumice is limited by the reducing action of the gases; (4) the slagged layer is removed by abrasion when the coke is pushed out; and (5) a large proportion of the iron in the coal can be removed by washing.

Study of the Factors Influencing Pouring Rates of Nozzles. E. C. Hite and E. E. Callinan. (Bulletin of the American Ceramic Society, 1939, vol. 18, Mar., pp. 80–85). The authors report on their investigation of the factors influencing the rate of flow of steel through 23 brands of nozzles made by American companies. These were divided into two groups, general-purpose nozzles made from ordinary refractory materials, and special nozzles having higher heat-resisting properties. Tests made with the first group showed that the teeming rate increased until about half of the heat was teemed and it then decreased, finishing at a rate slightly higher than the commencing rate. Tests made with the second group showed that the rate of teeming decreased fairly steadily the whole time. The authors explain this difference by pointing out that the general-purpose nozzles are eroded during the first part of the teeming to a shape inducing streamline flow, whilst the special nozzles are not eroded in this way. They discuss formulæ for calculating the rate of viscous flow and non-viscous flow, and conclude by suggesting that the ideal nozzle is one which will allow the steel to flow at a constant rate for the whole heat, and that this could be produced from a refractory with a Seger cone number between that of the general and special nozzles tested and so designed that the increase in size due to erosion balanced the decrease in flow due to loss of head as the ladle emptied.

Refractories for Bottom Cast Pouring. W. C. Kitto. (Bulletin of the American Ceramic Society, 1939, vol. 18, Mar., pp. 79–80). The author describes the refractories used for the nozzles and runners through which the steel is poured when bottom-casting ingots of killed steel. For the nozzle a magnesite brick 13½ in. long with a bore 1⅜ or 1½ or 1⅝ in. in dia. is used. He gives the analyses of three grades of runner brick the alumina contents of which vary from 35·58% to 43·57%. He stresses the importance of teeming at the correct temperature which, at the works in question, is 2900° F.

Pouring Pit Refractories as a Source of Non-Metallic Inclusions. D. L. McBride. (Bulletin of the American Ceramic Society, 1939, vol. 18, Mar., pp. 86–87). The author discusses the erosion of the

refractories forming the tapping spout of a steel furnace, and the lining and nozzle of the ladle, and shows that this is frequently the cause of non-metallic inclusions in ingots. He suggests the use of chrome-magnesite material for the tapping spout and states that there is urgent need of a material for the ladle nozzle capable of withstanding the attack of the metal and slag under teeming conditions.

Memoir about Steel Pouring Refractories. C. L. Kinney. (Bulletin of the American Ceramic Society, 1939, vol. 18, Mar., pp. 87–92). The author discusses the quality of the refractories now used for the lining of ladles and for ladle nozzles in steelworks. He relates this to the occurrence of inclusions in the ingots and suggests that ceramic and metallurgical technicians should co-operate in an endeavour to improve the refractories used for these purposes.

Bringing Insulation Facts up to Date. G. E. Grimshaw. (Heat Treating and Forging, 1938, vol. 24, Dec., pp. 625–629; 1939, vol. 25, Jan., pp. 40–43: Industrial Heating, 1939, vol. 6, Jan., pp. 61–65, 83; Feb., pp. 157–161; Mar., pp. 253–260). In the first part of this paper the author considers the respective merits of firebricks with a backing of insulating material and of fireclay bricks for use in gas-fired furnaces. From this he proceeds to a discussion of E. Schmidt's charts for calculating the temperature distribution in furnace walls. In the second part he deals with furnaces and ovens working at various temperatures between 200° and 1000° F. He describes the construction of the walls, the thermal and physical properties of the refractory materials used, and compares their advantages and disadvantages.

Insulating Firebrick. W. R. Kerr. (Steel, 1939, vol. 104, Apr. 3, pp. 42–46). The author discusses the properties of insulating firebricks which are used on the outside of the refractory walls of furnaces and suggests some of the requirements which should be included in the specifications when ordering these bricks.

FUEL

Fuels, with Special Reference to the Iron and Steel Industry—Value of Coal and Furnace Fuel Products. S. G. Ward. (Staffordshire Iron and Steel Institute, Mar., 1939 : Iron and Coal Trades Review, 1939, vol. 138, Mar. 24, pp. 531–532). After considering the factors effecting the selection of fuel for use in metallurgical furnaces, the author considers four fuel-consuming units, namely, coke-ovens, blast-furnace, melting furnaces requiring temperatures above 1600° C. and reheating and heat-treatment furnaces. He discusses next the effect of the ash content of coking coal and the effect of moisture in ores on the fuel economy of the blast-furnace. In the author's opinion more attention should be given to the treatment of the low-grade ores found in this country. In conclusion he discusses the use of briquettes made of duff coal, and perhaps partially gasified, in gas producers.

Flocculation and Clarification of Slimes with Organic Flocculants. G. R. Gardner and K. B. Ray. (American Institute of Mining and Metallurgical Engineers, 1939, Technical Publication No. 1052). The authors report on their investigation of methods by which cheap organic materials can be prepared for use as flocculating reagents for the purification of water from coal-washing plants. They find that any starch can be used to prepare a flocculating reagent, but they recommend potato starch. They describe the preparation of the flocculating solutions.

Position and Prospects of Coke-Oven Technique at November 1st, 1938. C. Berthelot. (Chimie et Industrie, 1939, vol. 41, Feb., pp. 224–233). The author reviews the present state of the development of the coal carbonisation industry in Europe and presents statistics respecting costs ; quantities of coke, gas and by-products produced ; oven dimensions and fuel-gas consumption.

Coke-Oven Plant of the Shelton Iron, Steel and Coal Company Limited. (Iron and Coal Trades Review, 1939, vol. 138, Apr. 7, pp. 617–618). A description is given of the battery of coke-ovens and the reconstructed by-product plant recently completed at the works of the Shelton Iron, Steel and Coal Co., Ltd. The battery consists of 24 Simon-Carves under-jet regenerative ovens with the Otto twin-flue system of vertical heating. The ovens are 38 ft. 6 in. long × 14 ft. 3 in. high and will carbonise a charge of 15·6 tons of dry coal in 18 hr.

Dangerous Swelling Pressures in Carbonisation Practice. G. E. Foxwell. (Institute of Fuel, Mar. 16, 1939 : Iron and Coal Trades Review, 1939, vol. 138, Mar. 24, p. 542). After stressing the importance of the proper selection and blending of coking coals the

author describes two standard methods in use on the Continent for determining the pressure-generating propensities of coking coals. The first apparatus, by Koppers, is so designed to record only pressures generated in the coal that are in excess of what is regarded as the permissible load upon a coke-oven wall, *i.e.*, in excess of 0·08 kg. per sq. cm. The second is the Nedelmann apparatus which registers the pressure set up by the coal and not the movement of the coal against a given force.

New Method of Quenching Coke by an Atomised Water Spray. S. M. Adon'ev and M. T. Tsygunov. (Koks i Khimiya, 1938, No. 1, pp. 17–18). (In Russian). The authors consider the volume of water and the number and type of spray nozzles required for a new method of quenching coke. A more rapid quench, a reduced volume of water, practically no phenol in the waste water and improved properties of the coke produced, are among the advantages claimed for this method.

New Producer Gasifies Inferior Coal. (Blast Furnace and Steel Plant, 1939, vol. 27, Mar., pp. 269–270). A description is given of the Daae gas-producer recently installed at the Monessen Works of the Pittsburgh Steel Co. It is claimed that the improved design of this producer enables inferior quality coal of high ash content and having a higher proportion of fines to be used. The Daae producer has a revolving grate and ash-pan which enables the ash to be removed continuously. Another feature is that only part of the blast is introduced at the centre, the remainder entering through a large number of small openings in the revolving grate.

PRODUCTION OF IRON

The Schack Tubular Recuperator for Heating the Blast for two Blast-Furnaces at the Pilsudski Works, Chorzów (Poland). (Génie Civil, 1939, vol. 114, Mar. 18, pp. 240–241). A description is given of a two-stage blast preheater which was put in operation in 1937 at Chorzów, Poland. This was also described in Stahl und Eisen, 1938, vol. 58, Oct. 6, pp. 1086–1089. (*See* Journ. I. and S.I., 1939, No. I., p. 10 A).

Steel Recuperators for Blast-Furnaces. O. Johannsen and A. Holschuh. (Fuel in Science and Practice, 1939, vol. 18, Mar., pp. 77–79). The authors describe the steel-tube recuperator which has been installed by the Röckling'sche Eisen und Stahlwerke for heating the blast-furnace blast. This recuperator was described more fully in Stahl und Eisen, 1938, vol. 58, July 7, pp. 721–727. (*See* Journ. I. and S.I., 1938, No. II., p. 130 A).

Calculating the Temperature of the Refractory Bricks in Blast Preheaters. H. Hausen. (Archiv für das Eisenhüttenwesen, 1939, vol. 12, Apr., pp. 473–480). The author gives an example of the application of heat-balance calculations to the determination of the temperature to which the refractories in a blast preheater of the reversible regenerative type will be subjected.

Blowing-in of the World's Largest Blast-Furnace at the Zaporozhstal Works. A. Romm. (Stal, 1938, No. 10, pp. 1–15). (In Russian). The author describes the blowing-in at the Zaporozhstal Works in May, 1938 of the 1300 cu. m. capacity blast-furnace. Its constructional details and the results obtained during the first two months of operation are described. Under favourable conditions the daily average output of the furnace reached 1348 tons; the relative consumption of coke during the same period amounted to 0·837 tons per ton of iron. Owing to careful preparatory work, no difficulties have been encountered during the blowing-in and early working of the furnace. The experience gained so far shows that the design may be regarded as satisfactory.

The Desulphurisation of Pig-Iron with Alkalies. I. The Reactions of Molten Pig-Iron High in Sulphur and Low in Silicon and Manganese with Soda and Sodium Silicates. W. Oelsen and W. Middel. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 2, pp. 27–55). The authors describe a laboratory investigation of the reactions which occur between molten iron high in sulphur, low in silicon and manganese and the slags formed by additions of soda and sodium silicates at temperatures between 1300° and 1400° C. The following conclusions were reached: (1) On a laboratory scale a single addition of soda produced a degree

of desulphurisation three times that produced on a full scale. When the final sulphur content was 0·008%, 1 kg. of pure soda removed 0·32 kg. of sulphur. (2) The sodium sulphide is stable at 1300–1400° C. and requires no solvent. A slag could be formed containing as much as 80% of sodium sulphide and at the same time the iron contained only 0·008% of sulphur. (3) The sodium sulphide readily dissolved any iron sulphide even when the sulphur content of the iron was quite low. (4) The carbon in the iron is a sufficiently powerful reducing agent to reduce the ferrous oxide in the slag to such an extent that, apart from the soda to remove the sulphur, no other reducing agent is required. (5) When pure soda is intimately mixed with the molten iron the reduction of the former, which is characterised by the formation of heavy fumes, is an indication that the desulphurisation is complete. These fumes also indicate, however, that the slag can still take up more sulphur. (6) Any addition of silica decreases the rate of desulphurisation and raises the limit to which desulphurisation can be carried. The effect of heat on the desulphurisation is also less when silica is added. (7) Sodium metasilicate is also an important desulphurising agent. (8) Even when silica is added, a considerable amount of the sulphur is removed by solution of the iron sulphide as well as by the soda. (9) It is better when using both soda and silicates to increase the proportion of the silicates later in the process so as to allow time for the highly basic slag to take up most of the sulphur from the iron. (10) The comparatively strong deoxidising action of the basic desulphurising slag on low-silicon iron is due to the very low ferrous oxide content of the slag. (11) The desulphurising action of sodium silicates is affected to an important extent by the temperature. Raising the temperature from 1200° to 1500° C. increases the final sulphur content of the iron by 100%.

The authors present the data obtained by their investigation in numerous tables and graphs.

The Reduction of Calcium Sulphate with Metallic Iron. D. Mirew. (Archiv für das Eisenhüttenwesen, 1939, vol. 12, Mar., pp. 429–431). The author describes his experiments by which he tested the validity of Finkener's equation

$$CaSO_4 + 4Fe = CaO + FeS + 3FeO$$

as this reaction is very important in connection with the desulphurisation of iron in the blast-furnace and the open-hearth furnace. He discusses the results of a number of experiments in which he reduced calcium sulphate with iron at temperatures of from 500° to 1200° C. He shows that the Finkener equation is incorrect because at high temperatures the calcium oxide will react with both iron sulphide and ferrous oxide. His conclusion is that the reaction which takes place is :

$$CaSO_4 + 4Fe = CaO.FeS + 3FeO \text{ (at up to 900° C.)}$$
$$\textit{or } CaSO_4 + 4Fe = CaO.FeO + FeS + 2FeO \text{ (at above 900° C.)}$$

The Reactions between High-Carbon Iron-Manganese Melts and Iron Oxides, Iron Sulphide and Silicates at from 1300° to 1400° C. (Laboratory Tests for the Production of High-Manganese Slags). W. Oelsen. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 5, pp. 79–103). The author's investigation was undertaken to determine the possibility of obtaining high-manganese slags from spiegeleisen and phosphoric spiegeleisen. He determined the analyses of the iron and the slag at the conclusion of reactions between manganiferous irons and mixtures or iron oxide and iron sulphide. The final manganese content of the iron determines the composition of the slag. As long as the final manganese content exceeds about 1%, the slag contains a predominating proportion of manganese sulphide and manganous oxide with very little ferrous oxide and ferrous sulphide, and such slags are therefore suitable (after roasting) for the production of ferro-manganese. Part of this investigation has already been reported in Stahl und Eisen, 1939, vol. 59, Jan. 26, pp. 81–87. (*See* Journ. I. and S.I., 1939, No. I., p. 207 A).

Determination of the Viscosity of Pig Iron and Cast Iron by the Torsion Process. O. Gessner. (Breslau Technische Hochschule, Dissertation, 1938). The author discusses the existing methods of determining the viscosity of liquids and their application to molten metals and alloys and then describes the viscosimeter which he himself developed. He tests this apparatus with liquids of known viscosity and finds its accuracy to be satisfactory. He then uses it to determine the viscosity of a number of molten foundry, hematite and charcoal irons and presents the results in tables.

Viscosity Determinations of Slag Systems. J. R. Rait, Q. C. M'Millan and R. Hay. (Journal of the Royal Technical College, 1939, vol. 4, Jan., pp. 449–466). The authors investigate the binary systems CaO–SiO_2 and MnO–SiO_2 and the ternary system CaO–Al_2O_3–SiO_2, and find that in the second of these three systems the viscosity decreases with increasing MnO, the eutectic mixture having the highest viscosity of the melts examined. The highly viscous nature of the siliceous slags has been attributed by Field to the polymerisation of the silicon molecules. A pronounced minimum occurs in the viscosity/composition isothermal curves at the compound CaO–SiO_2.

FOUNDRY PRACTICE

Forehearths. J. Thwaites and H. Davis. (Canadian Metals and Metallurgical Industries, 1939, vol. 2, Feb., pp. 30–31, 38). The authors discuss some points which should be observed in the design of forehearths to be used in conjunction with foundry cupolas. They recommend that the diameter of the forehearth should be approximately that of the cupola at the melting zone and that it is preferable to raise the cupola to give sufficient height to allow tapping from the spout at the bottom of the forehearth. They refer briefly to a new type of cupola spout used with success in Scotland. This spout consists of a special firebrick set in the breast of the cupola; the brick is similar to a teapot spout but it has three outlets, the top one being on a level with the surface of the molten metal in the cupola. The first cold iron is tapped from the bottom hole, but this is plugged when the iron has come up to temperature, thus forcing the metal from the top opening. The use of this spout reduces the risk of slag. The authors then describe a cylindrical tilting "teapot" ladle used by The International Harvester Co. of Canada, Ltd. The normal capacity of this ladle is about 2000 lb. and it is used in conjunction with a cupola melting about 7½ tons per hr. The treatment of the metal includes the addition of briquetted sodium carbonate to remove the sulphur. The authors describe the lining of the ladle in detail and discuss the advantages gained by its use.

On Cupola-Melting with Superheated Blast. E. Piwowarsky. (Giesserei, 1939, vol. 26, Apr. 7, pp. 169–174). The author describes a number of tests made with a cupola at the Aachen Technical High School with the object of determining the effect of superheating the blast on the coke consumption, melting rate, rate of sulphur removal, tapping temperature of the iron and composition of the waste gas. On the basis of the data obtained he presents two heat-balance calculations for the working of a cupola with a shaft area of about 1 sq. m., in one case with a metal recuperator for heating the blast to 600–700° C. and in the second case without a recuperator. The author's experiments and calculations clearly demonstrate the advantages to be derived by raising the blast temperature from 300° to 600–700° C.

The Laws Governing Cupola Melting. H. Jungbluth. (Giesserei, 1939, vol. 26, Mar. 10, pp. 113–120). In this mathematical treatise the author discusses the equations which express the relationships between the blast, the coke consumed, the melting time and the melting capacity of a cupola.

The Rôle of Heat-Resisting Alloys in Short-Cycle Malleablizing Furnaces. H. H. Harris. (Transactions of the American Foundry-

men's Association, 1939, vol. 46, June, pp. 832–849). The author discusses the design of rails, rollers, bearings and trays used in the construction of short-cycle malleablising furnaces.

Shop Problems in Low Carbon Iron. A. P. Lee. (Foundry, 1938, vol. 66, Dec., pp. 26–27, 72; 1939, vol. 67, Jan., pp. 28–29, 74). The author deals with some of the difficulties the foundryman experiences in the casting of low-carbon iron. He discusses the size and position of the gate in relation to the shape of the casting and refers to the use of gates made of firebrick when making large castings. The author also points out that to obtain a good finished casting it is often necessary not only that the foundry but also the machine shop adopt a special technique for the low-carbon iron.

Controlled Work Hardening. R. A. Prosser. (Steel, 1939, vol. 104, Apr. 3, pp. 56–58). The author describes the process of manufacturing manganese steel railway crossings as developed by an American foundry. The first casting is left with recesses into which 13% manganese steel pads are cast which will receive the "battering" of the wheels passing over the crossing. These pads are cast higher than the rail level and the surplus metal is ground off to insure that all decarburised metal is removed. The crossing is then work-hardened in the cold state by placing a specially shaped tool on the pad and subjecting this to steam-hammer blows. The final operation consists of removing the excess metal which the forging has caused to flow towards the points of intersection.

Composite Rolls. F. C. T. Daniels. (Steel, 1939, vol. 104, Mar. 13, pp. 63–66). The author describes briefly the manufacture, properties and applications of composite cast-iron rolls now being made by a Pittsburgh company. These rolls are cast in a manner similar to that employed for making chilled iron rolls except that the mould is first filled with the metal, which is to form the outer surface of the roll, and, after sufficient time has elapsed to allow it to solidify to the required depth, the liquid metal in the centre is displaced by teeming the molten iron of different analysis which is to make the tough core of the finished roll. With this casting process the surface hardness and the hardness depth can be varied within wide limits and the two metals bound together as one.

From what Iron are Moulds to be Cast? B. N. Svetchnikoff and K. F. Starodubov. (Stal, 1938, No. 11, pp. 41–46). (In Russian). The authors present a detailed review of the literature from 1931 to 1937 together with their own experimental results respecting investigations of the quality of iron for making ingot moulds, and they find that all investigations recommend the use of iron with a pearlitic structure, a fairly high-carbon content and with not too coarse graphite. The temperature at which the metal is cast should be about 1160–1190° C. The authors compared the life of moulds made of a ferritic-pearlitic type of iron with those of moulds made of pearlitic irons of two compositions, (1) silicon 1%, manganese 1%, and (2) silicon 1·6% and manganese 1·5%, and

found that the pearlitic iron moulds lasted two to five times as long depending upon the working conditions. In order to determine the structure of the iron without resorting to a microscopical investigation, the use of Maurer's diagram with corrections for the phosphorus and manganese contents is recommended. (*See* Journ. I. and S.I., 1937, No. II., p. 209 A).

Casts Diesel Engines for Trucks. P. Dwyer. (Foundry, 1939, vol. 67, Mar., pp. 22–25, 72, 75). The author describes the equipment of Mack Trucks Incorporated and the foundry technique employed by them for the casting of Diesel engine parts for motor lorries.

Pressure-Casting Machine for Cast Iron. (Foundry Trade Journal, 1939, vol. 60, Mar. 30, p. 267). A brief description with three diagrams is given of a pressure-casting machine for cast iron designed by J. de Sternberg. The pressure box of this machine is a steel chamber placed over a cylindrical crucible; the lower part of the crucible is formed by a metal piston capable of moving freely in the crucible and up into the pressure box. The design is such that it is only when the piston reaches the lower part of the pressure box that pressure begins to be imposed upon the mould; there is therefore never any pressure on the crucible wall. The time during which the steel pressure box is exposed to the action of the liquid metal is extremely short. Castings made with this machine show extremely smooth surfaces. Irons of normal composition cast in this machine have a white structure and if it is required to machine them a graphitisation treatment is necessary.

The Renfrew Foundries of Babcock and Wilcox. (Iron and Coal Trades Review, 1939, vol. 138, Mar. 31, pp. 583–590: Engineer, 1939, vol. 167, Mar. 31, pp. 402–403; Apr. 7, pp. 430–431: Engineering, 1939, vol. 147, Mar. 31, pp. 359–362: Foundry Trade Journal, 1939, vol. 60, Mar. 30, pp. 269–273). A full description with numerous diagrams and illustrations is presented of the Renfrew steel foundry of Babcock and Wilcox, Ltd., where reorganisation and extensions have recently been completed. Some particulars of the melting practice at this foundry are given in the following abstract.

Melting Practice in a Large Engineering Iron Foundry. W. W. Braidwood. (Foundry Trade Journal, 1939, vol. 60, Mar. 16, pp. 231–234, 240; Mar. 23, pp. 253–255, 258). The author describes the melting practice at the Renfrew Foundry of Babcock and Wilcox, Ltd., where castings for steam-raising plant and for general engineering purposes are produced. The melting plant comprises four cupolas melting 9–10 tons per hr., one melting 4 tons per hr., and an oil-fired crucible furnace. The author explains the principles of the balanced blast and from this proceeds to describe the fettling of the cupola lining with special reference to the influence of the setting of the tuyeres on the lining wear. He considers next the advantages and disadvantages of using metal receivers (which are

used at this foundry), the method of slag removal, the air supply system, the charging system, the method of transporting molten metal and the recording system for control purposes.

American Cast Iron Pipe Company. (Iron and Steel Engineer, 1939, vol. 16, Mar., pp. 24–25). A brief description is given of the works of the American Cast Iron Pipe Co. at Birmingham, Alabama, one of the largest pipe foundries in America. The centrifugal process is used at these works.

Abrasives and their Application in Foundry Practice. H. Bromage. (Foundry Trade Journal, 1939, vol. 60, Mar. 16, pp. 227–228). The author commences his discussion of abrasives by briefly describing the manufacture of three types of grinding wheel, namely, the aluminium oxide or "Bauxilite," the white Bauxilite and the silicon carbide wheels. He considers next resinoid- and rubber-process wheels, methods of mounting wheels, the choice of wheels for different purposes, and concludes by describing some of the grinding machines now available.

The "White Deposit" Defect in Large Iron Castings. A. Le Thomas. (Foundry Trade Journal, 1938, vol. 60, Mar. 16, p. 238). The author discusses a type of defect which occasionally appears only in large castings. It is generally discovered with the first blow of the fettling hammer which causes a white crust several millimetres thick to detach itself; the white crust is often found at the roots of teeth in large gear wheels, and close to the runners. The analysis of this white deposit is approximately: SiO_2 72·20%, Al_2O_3 2·56%, CaO trace, MgO trace, Fe_2O_3 6·52%, MnO 6·72%, S 1·37% and C 10·55%. In the author's opinion a certain amount of precipitation takes place while the iron is still in the liquid state in the mould, and the graphite, slag and manganese sulphide pass to the walls of the mould, reactions then take place between these and some of the elements in the moulding sand, the products of which solidify with the iron forming the white deposit. He concludes by explaining that the remedy is to control the composition of the iron which should be relatively low in silicon, sulphur and phosphorus and high in manganese; the quality of the scrap metal charged must therefore be watched.

PRODUCTION OF STEEL

Works of the Bethlehem Steel Company at Sparrows Point and Strip Mill at Lackawanna. (Iron and Coal Trades Review, 1939, vol. 138, Mar. 17, pp. 497–501). A description is given with numerous illustrations of the Bethlehem Steel Company's works at Sparrows Point and Lackawanna. The plant has an annual pig-iron capacity of 1,660,000 tons and a steel-ingot capacity of 2,467,000 tons.

A Comparison of English and German Open-Hearth Furnaces. F. Wesemann. (Stahl und Eisen, 1939, vol. 59, Apr. 13, pp. 450–457). The author compares the dimensions, consumption and production of English and German open-hearth furnaces. The differences to which he directs attention are : (1) In English practice bigger charges are needed and the pig iron contains more silicon and phosphorus ; (2) the mean depth of bath is much greater in English furnaces ; (3) in English practice the production per hour in proportion to the weight of the melt is lower, but in proportion to the hearth area is higher than in Germany ; (4) when the production per hour is the same the time required for refining is, for metallurgical reasons, much longer in English practice ; (5) the heat consumption is greater in English furnaces probably because of the greater quantity of slag and perhaps because of the different design of ports ; the design of the ports in the latest English tilting furnaces is now very similar to those used in German furnaces ; and (6) in English practice the consumption of refractories decreases with increased size of furnace and the material used for patching increases with the amount of lime charged and the amount of slag formed. The average figures for the consumption of refractory materials in the two countries are approximately equal.

Development in the Design and Thermal Characteristics of the Recuperative Steel Melting Furnace. E. Hofmann and M. Paschke. (Stahl und Eisen, 1939, vol. 59, Apr. 6, pp. 417–426). The authors describe the conversion of a 20-ton regenerative basic open-hearth furnace into a 30-ton recuperative furnace. The conversion was undertaken for the following reasons : (1) To reduce the consumption of heat by the more economic utilisation of the exit gas and by elimination of the heat loss to the walls of the regenerator chambers ; (2) to improve the flame propagation by the use of several mixing burners of improved design and by using air heated to 800–900° C. ; (3) to provide means of adjusting the furnace atmosphere to the metallurgical conditions ; and (4) to obtain complete elimination of air leakage by encasing the body of the furnace with sheet metal. Trials with the reconstructed furnace showed that various alterations

were required and this resulted in the final design being reached in five stages, each of which the authors describe with diagrams. With the recuperative type of furnace a better mixture of gas and air can be obtained, and, by suitably adjusting the velocity of the gases and the angle of the burners, the flame length can be controlled to suit the length of the furnace and no heat is wasted by some combustion taking place in the flues. This increase in efficiency reduces the required temperature of the air supply from 1200–1300° C. to 800–900° C., the latter being a permissible temperature for the steel tubes of the air preheater. It is thus possible to utilise some of the heat in the exit gas before it reaches the recuperator for steam generation. A small water-tube boiler with 17 sq. m. heating surface was incorporated in the design and this produced superheated steam at 15–17 atm. and 325–375° C., and this installation reduced the exit gas temperature from about 1700° C. to 1050° C. The authors present a number of heat balance diagrams which enable a comparison of the thermal efficiencies of regenerative and recuperative furnaces to be compared, and they develop a nomograph which enables the theoretical combustion temperature to be calculated from the effective calorific value of the coke-oven gas, the air supply and the air temperature.

The Melting of an Open-Hearth Charge Using Control Curves. L. P. Vladimirov. (Metallurg, 1938, No. 6, pp. 40–48). (In Russian). The author points out that the rate of carbon oxidation may be used as a basic factor in determining the duration of an open-hearth melt. Using semi-theoretical considerations, he constructs curves relating the rate of carbon removal to the carbon and free ferrous oxide contents. Knowing the carbon content required in the finished steel, as well as the initial carbon content, the ferrous oxide content can be adjusted to the value which will give the desired final carbon content in the time in which it is possible to raise the temperature of the metal after melting to the tapping temperature. Having selected the corresponding carbon-content/boiling-duration curve, it is possible by checking the carbon at suitable intervals to regulate the rate of carbon removal and, consequently, the melting time. In order to make this process possible the carbon content of the metal immediately after melting should be some particular optimum value, depending on the thermal capacity of the furnace.

"Tailor-Made" Steels. T. Grey-Davies. (Sheet Metal Industries, 1939, vol. 13, Feb., pp. 209–211, 220; Mar., pp. 359–360, 368; Apr., pp. 483–484, 490). Continuation of a series of articles (*see* Journ. I. and S.I., 1939, No. I., p. 212 A). The author continues his discussion of the physical chemistry of steelmaking, dealing in particular with the reactions between the steel and slag, and the process of desulphurisation. In Part IX. he considers the various types of ingots produced for manufacturing steel sheets, and the modifications in the control of the basic open-hearth process which

each quality of sheet demands. In Part X. he discusses the manufacture of rimming steel, declaring that at present the iron oxide content of the slag is the most generally used index to the state of oxidation of the steel bath. He describes how the iron oxide content of the slag is kept low and shows that this content does not increase as rapidly in a high-silica slag as in a low-silica slag.

Properties and Metallurgical Uses of Calcium. C. L. Mantell and C. Hardy. (Metals and Alloys, 1939, vol. 10, Feb., pp. 52–56; Mar., pp. 96–100). After describing in Part I. the production and properties of calcium, the author discusses in Part II. the metallurgical uses of metallic calcium. Its use with regard to iron and steel is mainly as a deoxidiser and degasifier. One method of adding the calcium is to shoot it into the ladle of molten metal with a compressed-air gun, and by this method a 60-ton ladle of steel can be deoxidised in about 5 min. using about 2 lb. of calcium per ton of steel. Calcium is now used in the manufacture of chromium-nickel steels as it gives clean grain boundaries, uniform grain size and retards the formation of carbides.

The Production of Stable Stainless Steel. (Metallurgia, 1939, vol. 19, Mar., pp. 187–189). The causes of the intercrystalline corrosion at high temperatures of 18/8 stainless steel are discussed in detail and the primary cause is declared to be the low solubility of carbon in the alloy at temperatures below 600–700° C., for the carbon which separates out combines with the chromium to form chromium carbide which is unstable. A number of attempted methods of producing a stable stainless steel are described and their disadvantages, chiefly with regard to cost, are pointed out. The ideal solution to the difficulty would be to produce the stainless steel with a carbon content not exceeding 0·03%. It is now claimed by S. Westberg of The Refined Stainless Steel Co., Ltd., that he has found a commercially successful method of making such a steel. No information is given as to the process, but it is claimed that sheets and cold-rolled strip of this new material have successfully passed the stability tests of Hatfield and Krupp as well as that of the British Air Board. In conclusion the technique to be employed for welding this steel with the oxy-hydrogen flame is described.

Some Notes on the Early Manufacture of Stainless Steel in the United States. F. Garratt. (Iron Age, 1939, vol. 143, Mar. 16, pp. 28–29). The author recalls some particulars relating to the two first stainless steel ingots to be cast in the United States. This was done under the author's direction in the metallurgical laboratory of the Firth–Sterling Steel Co. in 1914. The ingots weighed about 9 lb. each and contained 13·94% and 15·42% of chromium, respectively.

The Origin and Development of Stainless Steel. V. N. Krivobok. (Blast Furnace and Steel Plant, 1939, vol. 27, Mar., pp. 271–274). The author reviews the history of the manufacture of stainless steel. (*See* Journ. I. and S.I., 1939, No. I., p. 343 A).

A New Steelmaking Process. V. C. Faulkner. (Foundry Trade Journal, 1939, vol. 60, Mar. 23, pp. 248–250). The author describes the operation of two 5-ton Sesci rotary furnaces at the Crewe steel foundry of the London, Midland and Scottish Railway Co. These furnaces are fired with pulverised fuel, bituminous coal being used for starting up until the recuperators have reached a predetermined temperature. A small proportion of anthracite is introduced when the preheated air reaches a temperature of 100° C. and this is gradually increased and the bituminous coal decreased until anthracite only is used. He also gives particulars of the preparation and fettling of the refractory linings of the furnaces.

Contribution to the Duplex Process : Basic Bessemer Converter—Electric Arc Furnace. R. Graef. (Stahl und Eisen, 1939, vol. 59, Mar. 30, pp. 385–395). After a brief historical survey of the development of the duplex process of steelmaking, the author explains the metallurgical aspect of the process of completing the refining of basic Bessemer steel in an electric arc furnace. He points out the advantages of raising the carbon by the addition of coke on emptying the converter. The removal of the phosphorus takes 50–60 min. with a current consumption of 80–125 kWh. per ton of steel, and the desulphurisation down to 0·020% max. of hard steel takes 55–65 min. and for mild steel a little longer, whilst the current consumption for the latter is 70–110 kWh. per ton. The rate of deoxidation is adjusted to suit the quality of the steel required. No deleterious effect due to nitrogen has been observed with this process. The consumption of graphite electrodes amounts to 1·5–3·0 kg. per ton of steel. The author discusses the factors affecting the rate of electrode consumption and shows that during the deoxidation an increase in the voltage reduces the electrode consumption but increases the time required for the reaction. Conversely, lowering the voltage increases the electrode consumption, whilst the rates of desulphurisation and deoxidation are increased. The author recommends pressing in dolomite stone for facing the lining of large electric arc furnaces as this method requires much less time than ramming. The hearth of an electric furnace working the duplex process lasts about 2500 melts.

Small Ingots. D. V. Hamilton. (Canadian Metals and Metallurgical Industries, 1939, vol. 2, Feb., pp. 27–29). The author describes the electric furnace process in use at the Montreal Works of Canadian Tube and Steel Products, Ltd. The furnace used is an improved Heroult basic-lined furnace producing steel with sulphur and phosphorus limits of 0·035%. With regard to teeming, the author shows that in some cases it is necessary to provide a refractory hot top or collar to the ingot mould, and the metal in this has a freezing rate about half of that of the metal in the mould below. If this refractory lined head is properly insulated the ingot proper will solidify with ample molten metal above it to fill up the cavity.

Influence of the Wall Thickness of the Mould on the Solidification and Quality of a Steel Ingot. I. Ya. Granat and A. A. Bezdenezhnykh. (Metallurg, 1938, No. 10, pp. 19–33). (In Russian). Prior to the study of the solidification of 7-ton ingots with the object of improving the mould design, the authors studied the effect of mould-wall thickness on the solidification process. For this purpose a vertical circular mould (with internal diameter varying from 650 mm. to 920 mm. and height 2300 mm.) was used, a wall thickness varying from 240 to 80 mm. being obtained by the out-of-centre position of the cylindrical interior. The rate of cooling of the steel near the 240- and 80 mm.-thick mould walls was studied by temperature measurements, by means of suitably protected platinum/platinum-rhodium thermocouples which had been passed through the walls and made to protrude 3 cm. into the interior. Calculations based on the cooling curves obtained showed that during solidification the thin wall removed more heat from the molten metal than did the thick mould wall. This was also confirmed by examination of the structure of the ingot. The process of solidification in the 7-ton industrial rectangular ingot mould was studied by temperature measurements by means of thermocouples let into the walls at different levels. Curves showing temperature distributions in the mould walls and heat losses from various parts of the mould, as solidification progressed, were obtained. Defects, in particular piping, of the ingots was traced to incorrect mould design. The design should provide an increase in wall thickness from bottom to top with no, or only a minimum, taper in the same direction.

Investigation of a Rimming Steel Ingot. A. Botov and Sobornova. (Metallurg, 1938, No. 10, pp. 12–18). (In Russian). A 3-ton ingot of mild rimming steel (carbon 0·07%, manganese 0·33%, phosphorus 0·059%, sulphur 0·030%) was studied. The heat was deoxidised with ferro-manganese and by the addition of some aluminium to the moulds. The investigation included a study of the types of non-metallic slag inclusions and their distribution, macro- and microscopical examination and a study, by means of chemical analysis, of the segregation of the elements carbon, silicon, manganese, phosphorus, sulphur, nitrogen and arsenic. The chief defects in the ingot were the large quantity of slag inclusions and the high nitrogen content, which was irregularly distributed throughout the ingot and reached 0·0313% in some parts.

ROLLING-MILL PRACTICE

Working Methods and Times in Multi-Stage Deformation. L. Weiss. (Stahl und Eisen, 1939, vol. 59, Apr. 6, pp. 426–429). In a mathematical discussion the author develops a number of equations for calculating the number of passes, the degree of reduction obtainable at each pass and the time required for the rolling of steel sections.

Approved Roll Grinding Practice. H. J. Wills. (Steel, 1939, vol. 104, Mar. 20, pp. 46–48). The author enumerates several roll-grinding defects such as hammering or chatter, scratches, diamond marks, traverse marks, eccentricity and burning, and discusses their cause and remedy. He also describes a system of keeping a record of the life of a grinding wheel.

Roll Neck Bearings of Synthetic Resin Plastic. J. Arens. (Demag News, 1939, vol 13, Mar., pp. 1–20). An English translation of an article which appeared in Stahl und Eisen, 1939, vol. 59, Feb. 23, pp. 213–224. (*See* Journ. I. and S.I., 1939, No. I., p. 277 A).

Fractures of the Journals of Cold Rolling Mills. H. Sedlaczek. (Stahl und Eisen, 1939, vol. 59, Mar. 16, pp. 338–339). In the conversion from plain to roller bearings in a cold-rolling mill it is usually found that owing to lack of space the diameter of the journals has to be reduced, and this has often led to fractured journals. The author develops a formula for calculating the bending moment in the journals, given the pressure exerted at the centre of the rolls and their dimensions. He shows where the fracture nearly always occurs and describes and illustrates a method of radiusing the roll neck so as to prevent fractures.

Adds 44″ Blooming Mill. (Steel, 1939, vol. 104, Mar. 27, pp. 43–44, 76). A brief description and illustrations of the new mill for rolling blooms at the Hamilton Works of The Steel Company of Canada, Ltd., are presented. This is a two-high reversing mill stand with rolls 40 in. in dia. × 96 in. long driven by a 7000 h.p. D.C. motor. The roll-neck bearings are of synthetic resin with which excellent results are still being obtained in the existing 34-in. mill.

New Edgar Thomson Slabbing Mill has Interesting Features. (Blast Furnace and Steel Plant, 1939, vol. 27, Mar., pp. 255–257 : Iron Age, 1939, vol. 143, Feb. 9, pp. 46–47 : Steel, 1939, vol. 104, Feb. 20, pp. 50–54). A description with several illustrations is presented of the new slab rolling mill at the Edgar Thomson Works of the Carnegie–Illinois Steel Corporation where slabs up to 60 in. wide can be rolled. The mill will take ingots up to 32 × 66 × 90 in. weighing 45,000 lb. Each of the two 45 × 80 in. horizontal rolls

is driven by 5000 h.p. motor and the vertical rolls by one 3000 h.p. motor. The screw-downs, the front and back mill tables, the manipulator and the slab shear are operated by Ward–Leonard control.

Continuous Sheet Bar and Billet Mill Installed at A. I. & S., Ltd. Kembla Works. (Broken Hill Proprietary Review, 1939, vol. 16, Feb., pp. 8–9). A brief description is given of the new sheet bar and billet mills which were put in operation in 1938 at the Kembla Works of Australian Iron and Steel, Ltd.

A Glimpse of the Light Rolling Mills at the Grusonwerk. E. Käftel. (Technische Mitteilungen Krupp, Technische Berichte, 1939, vol. 7, Apr., pp. 36–41). The author describes the alterations and improvements which have been made in recent years in the rolling-mill plant at Krupp's Grusonwerk.

Modern Methods of Hot Strip Production at Corby. (Sheet Metal Industries, 1939, vol. 13, Mar., pp. 361–364). A detailed description is given of that part of the rolling-mill plant at the Corby works of Stewarts and Lloyds, Ltd., which is devoted to the rolling of skelp for tube making.

Advancements in Foreign Rolling-Mill Practice. (Stahl und Eisen, 1939, vol. 59, Apr. 13, pp. 459–461). A description is given of the cold-strip mill and annealing plant of the Indiana Steel Co. at Indiana Harbor.

The Course of Deformation in the Pilger Mill Cold-Rolling Process and in the Piercing Mill. H. Unckel. (Archiv für das Eisenhüttenwesen, 1939, vol. 12, Mar., pp. 423–428). In order to study the flow of metal in the manufacture of tubes in the Pilger mill and the piercing mill, the author used brass and aluminium tubes as raw material on the surfaces of which a network of squares was scratched. He found that in the cold rolling the extension of the metal at the inner and outer surfaces of the tube was equal, but, when cold drawing, the metal at the inner surface was drawn in advance of that forming the outer surface. He also studied the effects of the two processes on the mechanical properties and crystalline structure of the material.

Hot Shear Blades. M. Riddihough. (Iron and Steel, 1939, vol. 12, Mar., pp. 341–342). The author describes briefly the manufacture of special shear blades for shearing hot billets. The body of the blade is made of mild or cast steel with a recess where the cutting edge is to be. This recess is filled up with the softest of the Deloro Stellite alloys by the oxy-acetylene welding process; this alloy has a low tungsten content and a pyramid diamond hardness of 400. It is claimed that the very long life of these blades more than compensates for their extra cost.

HEAT TREATMENT

An Introduction to the Heat Treatment of Steel. H. P. Nielsen. (Heat Treating and Forging, 1939, vol. 25, Mar., pp. 129–133). The author explains in simple language the iron-carbon diagram and describes the changes which occur during the cooling of steels containing in one case 2·0% and in another case 0·3% of carbon. He also briefly explains what is meant by spheroidising, full annealing, normalising, hardening and tempering.

Surface Heat Losses. J. G. Coutant. (Iron Age, 1939, vol. 143, Mar. 23, pp. 42–46). The author discusses the factors which influence the loss of heat to atmosphere from the outside walls of furnaces and presents a table showing the amount of heat lost per sq. ft. of wall surface per hr. at any wall temperature between 100° and 700° F. to still air at 80° F. He also gives examples of methods of calculating the outside wall temperatures for different qualities and thicknesses of refractories used for heat-treatment furnaces.

Universal Apparatus for the Surface Treatment of Metals in a Controlled Atmosphere. A. Smirnov. (Stal, 1938, No. 7, pp. 66–70). (In Russian). A small compact apparatus for use in small heat-treatment shops or for laboratory work has been developed. A gas pressure of 10 cm. of water was used in the apparatus which enabled the treatment of metals in various gases to be easily and accurately carried out, *e.g.*, the gas carburising of steel, the nitriding, cyaniding, bright annealing at different temperatures of steels and non-ferrous metals and the annealing of transformer steel in hydrogen. The apparatus described included the equipment necessary for the preparation of the various gas mixtures.

Controlled Annealing. R. M. Drews. (Steel, 1939, vol. 104, Mar. 20, pp. 62–64, 73). The author describes the annealing furnace installed by the Bolt and Nut Division of The Republic Steel Corporation. This furnace is approximately 9 ft. square and 10 ft. high and is lined with 9 in. of firebrick. It is fired with natural gas passing through 4-in. dia. radiant combustion tubes. The whole furnace can be raised and lowered on guide posts. The charge, usually consisting of coils of 4000–6000 lb. of bolt stock, is enclosed under a heating cover 8 ft. high × 5 ft. dia. The rates of heating and cooling can be very closely controlled with this equipment and the desired grain size and hardness can be produced to render the steel suitable for cold heading and subsequent machining.

Circular Annealing Covers. J. L. Whitten. (Steel, 1939, vol. 104, Mar. 20, pp. 52–54). The author describes the annealing

plant at the works of The Superior Steel Corporation, Carnegie, Pennsylvania. This plant comprises three vertical, cylindrical, gas-fired, heating units each fitted with 12 vertical radiant tubes 6 ft. long and 4½ in. outside dia. There are three bases and three inner covers to each furnace. They are used for annealing coils of strip which can be stacked to a height of 7 ft., the average charge weighing 16,000 lb. A cover is lowered over the charge and rests in a liquid seal at the base and the furnace is lowered over the cover. By planning a proper sequence of operations, the furnaces are always usefully employed in heating charges while the other bases not covered by a furnace are either cooling or being charged or unloaded. The time required to anneal a 16,000 lb. charge of low carbon steel is about 16 hr. and the time for cooling to 250° F. under the inner cover is about 24 hr. Water sprays are used to accelerate the cooling after the first 12 hr. Cracked natural gas is used for the protective atmosphere. The costs of annealing have been enormously reduced by the introduction of this plant.

Heating Rates for Processing Alloy Steels. S. F. Magis. (Iron and Steel Engineer, 1939, vol. 16, Mar., pp. 17–19). The author discusses the effects of different rates of heating upon the structure and hardness of alloy steels when these are being annealed or hardened.

Gas-Fired Hood Furnaces for Sheet Steel Annealing. (Sheet Metal Industries, 1939, vol. 13, Mar., pp. 365–366). A description is given of an installation for the annealing of steel sheets. It consists of a rectangular furnace equipped with vertical hot tubes, burners and a lifting device, a number of brick-lined bases on which the sheets are stacked and an equal number of corrugated inner covers which are kept over the charge during the cooling period after removal of the furnace. A fitting which has lowered the consumption of the heating gas consists of a chain carrying a number of star-shaped refractory baffles which are suspended inside the vertical radiant tubes; these baffles are known as "core-busters." In a typical plant a charge of 15–20 tons of sheets is heated up to 700° C. in about 12 hr., the burners are then shut off and the charge allowed to soak for a further 6 hr. The furnace cover is then removed, leaving the charge still protected by the inner cover which is left on until the temperature is down to 150° C. This type of installation is now widely used in the United States, but many have been laid down in South Wales and they are now being supplied to Canada, India and Japan.

Heating Rates of Strip Steel and Tinplate Products. A. G. Fisher. (Iron and Steel Engineer, 1939, vol. 16, Mar., p. 14). After enumerating the items which require particularly careful control in the heat treatment of sheets and tinplates, the author presents tables showing the highest average heating rates employed in oil- and gas-fired furnaces at the Sparrows Point Works of the Bethlehem Steel Company.

New Stress-Relieving Furnace Suitable for High and Low Temperatures. (Iron and Coal Trades Review, 1939, vol. 138, Apr. 7, p. 628 : Foundry Trade Journal, 1939, vol. 60, Apr. 13, p. 305). An illustrated description is given of a stress-relieving furnace installed at the Dukinfield Works of Daniel Adamson and Co., Ltd. The furnace is 36 ft. long × 14 ft. high × 14 ft. wide and it is intended for the heat treatment of pressure vessels weighing up to 30 tons. The furnace is heated by gas from 36 low-pressure burners of the automatic-proportioning type. The vessel to be treated is placed on a low bogie which is hauled into the furnace. The lining of the furnace is of a light-weight refractory material backed up with diatomaceous earth.

Report of Steel Division Committee on Heat Treatment of Steel Castings. (Transactions of the American Foundrymen's Association, 1938, vol. 46, pp. 871–876). In this Report of the Heat Treatment of Steel Castings Committee of the American Foundrymen's Association a brief account is given of some significant developments made known in 1937 respecting the furnaces used for the heat treatment of steel castings and heat treatment technique.

Furnaces for Hardening and Other Heat Treatment at the Works of Husqvarna Vapenfabriks Aktiebolag. S. Törnebohm. (Teknisk Tidskrift, 1939, vol. 69, Mar. 18, Mekanik, pp. 29–35). (In Swedish). The author describes with numerous photographs and diagrams some of the heat-treatment furnaces at the works of Husqvarna Vapenfabriks Aktiebolag, a company manufacturing small arms, bicycles, sewing-machines, &c. There are 140 furnaces, all are electrically heated and many of them are fitted with automatic temperature control.

WELDING AND CUTTING

An Electric Welding Machine with a Leakage Field. H. Langkau. (Zeitschrift des Vereines deutscher Ingenieure, 1939, vol. 83, Mar. 25, pp. 357–362). The author gives a detailed description of a new German electric-welding machine in which the voltage inertia is eliminated by the excitation of additional leakage fields. A marked increase in efficiency is claimed for this machine.

Arc Welding Using Paired Electrodes. V. S. Volodin and M. I. Kunis. (Vestnik Metallopromyshlennosti, 1938, No. 10, pp. 43–44). (In Russian). The authors describe a method of welding in which two bare electrodes are suitably spot-welded together side by side and, after coating, are used in the usual way inclined at an angle of 15° to 20° to the vertical for arc welding. In this position the end of one electrode will be further away from the work and the arc, taking the path of least resistance, will pass between the work and the end of the other electrode. As soon as the latter has melted away sufficiently, the arc will strike over to the end of the other electrode and will continue to wander from one electrode to the other during welding. Among the numerous advantages claimed for this new method are, of course, more rapid melting, less heating of the electrodes, a more stable arc and less spattering of the metal than with ordinary single electrodes. Electrode ends can also be utilised by butt-welding them on to the ends of new paired electrodes.

Flash-Butt Welding of Alloy Steel Tubes. W. Denker. (Stahl und Eisen, 1939, vol. 59, Mar. 30, pp. 396–398). The author discusses the process of welding alloy steel tubes by the flash-butt welding process. He shows that a high upsetting pressure must be applied just as with ordinary steel tubes. One of the difficulties encountered is that the increased pressure of the air inside the tube causes oxidation of the weld especially in the case of a chromium-steel tube, but this can be prevented by surrounding the weld with a protective atmosphere.

Welding Chromium and Chromium-Nickel Corrosion- and Heat-Resisting Steels. W. Spraragen and G. E. Claussen. (Welding Journal, 1939, vol. 18, Mar., Supplement, pp. 65–107). The authors review the literature to July, 1937, on the autogenous and electric welding of chromium-nickel steels and present a bibliography with 302 references.

Data on Spot Welding of 18–8 Stainless Steel to Yellow Brass. F. R. Hensel, E. I. Larsen and E. F. Holt. (Welding Journal, 1939, vol. 18, Mar., pp. 167–175). The authors report on their investigation of the factors affecting the properties of resistance-welds of 18/8 stainless steel to 66/34 brass. They found that it is

possible to join the two metals and obtain a reasonable strength of weld, and that the material and shape of the electrode tips have a very important influence upon the quality of the weld.

Composites of Plain and Alloy Steels Produced by Carbon Arc Process. R. E. Kinkead. (Iron Age, 1939, vol. 143, Feb. 16, pp. 36–41). **Manufacture of Composite Metals by Carbon Arc Welding.** (Metallurgia, 1939, vol. 19, Mar., pp. 169–172). **Composite Metals by Carbon-Arc Welding.** (Metal Progress, 1939, vol. 35, Feb., pp. 135–140). The author describes an application of carbon-arc welding by which a coating of special steel can be applied to sheets of ordinary carbon steel. This article appeared also in Steel, 1939, vol. 104, Jan. 30, pp. 39–41, 68. (*See* Journ. I. and S.I., 1939, No. I., p. 291 A).

Chain Manufacture—An Important Application of Resistance Welding. (Welding Industry, 1939, vol. 7, Mar., pp. 69–71). Descriptions are given of an automatic wire bending and lacing machine, a semi-automatic resistance chain welder, a trimming machine for removing fins and a chain testing and calibrating machine. Some particulars are given of the production capacity of the welding machines for various diameters of wire; using $\frac{1}{8}$-in. dia. wire the machine will make 25 welds per min. and 1200 welds per kWh., and for $\frac{1}{2}$-in. dia. chain the corresponding figures are 10 welds per min. and 180 welds per kWh.

Furnace Brazing of Cast Iron. H. M. Webber. (Iron Age, 1939, vol. 143, Feb. 2, pp. 55–57; Mar. 16, pp. 30–35; Apr. 6, pp. 46–48). Continuation of a series of articles. (*See* Journ. I. and S.I., 1939, No. I., p. 165 A). In the ninth article of this series the author describes the precautions which should be observed when furnace-brazing cast iron and the causes and methods of preventing distortion. In the tenth article he considers the factors affecting the selection of equipment for furnace-brazing, and in the concluding part he summarises the information previously presented by giving a table of troubles and their cure.

Saving Material by Suitable Design. A. Thum. (Wissenschaftliche Abhandlungen der deutschen Materialprüfungsanstalten, 1939, vol. 1, No. 2, pp. 32–40). In this discussion on the design of steel structures and machine parts with particular reference to welding, the author shows how it is possible not merely to save weight by using less material, but also in many cases to increase the strength.

The Factors which have to be Considered in the Design of Welded Joints. O. Graf. (Wissenschaftliche Abhandlungen der deutschen Materialprüfungsanstalten, 1939, vol. 1, No. 2, pp. 19–32). The author considers to what extent the results of laboratory tests of the strength and deformation properties of welded joints and of weld metal may be applied to the design of joints in highly stressed beams. He describes and illustrates a number of fractures in welds in structural steel and discusses their causes.

Determining the Safety Factor for Welded Structures. (On the Basis of Mechanical Tests). W. Kuntze. (Wissenschaftliche Abhandlungen der deutschen Materialprüfungsanstalten, 1939, vol. 1, No. 2, pp. 11–18). The author considers some instances of failures emanating from the weld in welded steel structures in which the strength of the structure proved to be less than the designed strength. He also discusses the value of notched-bar impact tests and bend tests as a means of determining the behaviour of structural steel and of weld metal in service.

The Testing of Welds. R. Berthold. (Wissenschaftliche Abhandlungen der deutschen Materialprüfungsanstalten, 1939, vol. 1, No. 2, pp. 81–88). In this explanation and discussion of the methods of testing welds by X-rays the author seeks to arouse the interest of steel fabricators in the value of the process whilst at the same time pointing out its limitations.

A New Method of Testing Welds. R. Berthold and F. Gottfeld. (Wissenschaftliche Abhandlungen der deutschen Materialprüfungsanstalten, 1939, vol. 1, No. 2, pp. 88–90). The authors describe the apparatus required, the applications and the limitations of the magnetised powder method of testing welds.

The Meaning and Extent of the Non-Destructive Testing of Welds. R. Berthold. (Wissenschaftliche Abhandlungen der deutschen Materialprüfungsanstalten, 1939, vol. 1, No. 2, pp. 80–81). The author discusses briefly the development of the methods of testing welds by means of X-rays and the magnetic powder method, and reproduces maps which show the distribution throughout Germany of the material testing stations at which apparatus for these two methods is available.

Notes on the Testing of the Fissure-Formation Tendency of Welds in Thin Sheets by means of the Focke-Wulf Clamping Device. O. Werner. (Wissenschaftliche Abhandlungen der deutschen Materialprüfungsanstalten, 1939, vol. 1, No. 2, pp. 75–79). The author considers some objections raised by F. Bollenrath and H. Cornelius to the use of certain types of clamping devices for the measurement of the stresses in welded steel sheet. (*See* Journ. I. and S.I., 1937, No. II., p. 142 A). He describes some tests made using the Focke-Wulf and J. Müller's clamping devices which showed that the thinner the steel sheet the greater are the contraction stresses and that the higher the speed of welding the lower are the contraction stresses.

The Relationship between Welding Technique and Mechanical Properties. G. Bierett. (Wissenschaftliche Abhandlungen der deutschen Materialprüfungsanstalten, 1939, vol. 1, No. 2, pp. 65–70). The author discusses the strength properties of welds in relation to stresses along the weld, across the weld and to shear stresses. He describes the technique (which includes the subsequent heat treatment) to be followed when making welds which will be subjected to these stresses, and concludes by considering

the heat treatment for the prevention of hardness and residual stresses.

Testing the Weld Sensitivity of Structural St. 52 on Bend-Test-Pieces with Longitudinal Beads. G. Bierett and W. Stein. (Wissenschaftliche Abhandlungen der deutschen Materialprüfungsanstalten, 1939, vol. 1, No. 2, pp. 71–74). This article appeared in Stahl und Eisen, 1938, vol. 58, Apr. 21, pp. 427–431. (*See* Journ. I. and S.I., 1938, No. II., p. 23 A).

Physical Properties of the Iron-Nickel Alloys Formed in the Welding of Nickel-Clad Steel. W. G. Theisinger and F. G. Flocke, (Welding Journal, 1939, vol. 18, Mar., Supplement, pp. 108–112). The authors report on the results of tensile and hardness tests on electrically welded joints in nickel-clad steel plate and describe the welding technique which should be employed to produce high-quality welds in nickel-clad steel plates.

Carburized Welds. E. J. Wellauer and G. C. Doehler. (Welding Journal, 1939, vol. 18, Mar., pp. 163–166). The authors present the results of microscopic examinations and hardness tests on butt-welded specimens of a 3½-% nickel steel which had been case-hardened. Four different kinds of welding rod were used and the specimens were carburised for 10 hr. at 1700° F. in a retort furnace using a gaseous carburising medium. They found that there was no important difference in hardness between peened and unpeened welds. The nickel steel rods used produced a case-hardened weld-metal surface which matched the hardness of the parent metal sufficiently well for most practical purposes. Considerable grain-coarsening occurred in the weld metal and the structure was not refined by a single quench so that when a maximum toughness of core is required a double quenching treatment is recommended.

The Investigation of Butt-Welded Plated Sheets. G. Richter. (Wissenschaftliche Abhandlungen der deutschen Materialprüfungsanstalten, 1939, vol. 1, No. 2, pp. 45–59). The author presents a detailed report on the properties of butt-welded joints in steel sheets coated with one of the following metals and alloys, namely, copper, nickel, *V2A* and Remanit 1880*S*. Both electric and oxy-acetylene welds were examined and the tests made included tensile, bend, fatigue and corrosion tests, chemical analyses and examinations with the microscope. In general, the results showed that welded joints with good strength and corrosion-resistance properties could be made by a skilled welder. In particular, the author notes that both the electric and the autogenous processes produce good results and that the final nickel coating when welded by the latter process had less iron in it than when the former process was used.

Defects at the Root of Butt Welds in Welded Steel Structures. W. Kolb. (Wissenschaftliche Abhandlungen der deutschen Materialprüfungsanstalten, 1939, vol. 1, No. 2, pp. 91–95). The author discusses the results of an investigation of the causes of slag inclusions and cavities at the root of butt welds in steel structures. He deals

in particular with the profile of the faces to be welded and recommends that when possible the two faces should form a fairly open X and that the surfaces should be finished with either a profile milling cutter or a grinding disc. He presents a series of 25 diagrams of different kinds of joints with an X-ray photograph of each.

Fatigue Tests of Butt Welds in Structural Steel Plates. W. M. Wilson and A. B. Wilder. (University of Illinois, Engineering Experiment Station, Bulletin No. 310, 1939). The authors report on an investigation of the fatigue strength of electrically welded butt joints in 21 specimens of carbon steel and 6 specimens of silicon steel (Si 0·23%). The fatigue strength of the welded joints was arbitrarily taken as the maximum stress to which a specimen could be subjected 2,000,000 times without failure. The results indicate that: (1) The fatigue strength of the joints in carbon-steel plates in the "as-welded" condition is reduced by the stress concentration at the edge of the weld due to the change in section, and it can be increased by planing off the excess weld metal; (2) peening the beads has almost no effect, and stress relieving by heat treatment has but little effect upon the fatigue strength of the welds; (3) the carbon-steel welds, with the exception of the automatic carbon-arc and stress-relieved welds show an appreciable increase in hardness in the heat-affected zone of the base plate. The silicon-steel welds exhibit a greater hardness in the heat-affected zone than the carbon-steel welds, but they are not excessively hard; and (4) the weld metal in silicon-steel specimens is not as hard as the heat-affected zone of the base plate, and in the case of carbon steel the hardness values are equal to, or slightly exceed, those obtained in the heat-affected zone of the base plate.

Notes on the Fatigue Strength of Welded Joints in Fabricated Lattice Girders of Overhead Cranes. E. vom Ende. (Wissenschaftliche Abhandlungen der deutschen Materialprüfungsanstalten, 1939, vol. 1, No. 2, pp. 41–44). The author considers several types of welded joints used in the fabricating of lattice girders for overhead cranes, and discusses the results of fatigue and tensile tests on joints made by welding on flat strap plates and their application to the design of the joint.

The Fundamental Principles of the Fatigue Strength of Welded Test Specimens and Brittle Materials in General. W. Gehler. (Wissenschaftliche Abhandlungen der deutschen Materialprüfungsanstalten, 1939, vol. 1, No. 2, pp. 1–11). In this mathematical discussion the author considers the application of the results of laboratory fatigue and impact tests to the design of engineering structures.

CLEANING AND PICKLING OF METALS

Planning and Equipment of a Modern Pickling Plant. (Sheet Metal Industries, 1939, vol. 13, Apr., pp. 491–492). An illustrated description is given of the new pickling plant installed at the West Bromwich Works of J. B. and S. Lees, Ltd., for pickling lengths and coils of strip.

Pickling in a Modern Enamelling Plant. (Sheet Metal Industries, 1939, vol. 13, Feb., p. 264). A brief description is given of the pickling plant of Sidney Flavel and Co., Ltd., Leamington, in which the sheets used for making domestic cooking ranges are prepared prior to enamelling.

Pickling with Regenerated Sulphuric Acid. P. Dickens. (Stahl und Eisen, 1939, vol. 59, Mar. 23, pp. 364–370). The author describes a laboratory investigation of the effect of ferrous sulphate on the rates of solution of iron and mill scale in sulphuric acid. He found that the presence of ferrous sulphate reduced the rate of attack on an iron surface but increased the rate of solution of mill scale and its presence was therefore beneficial to the pickling process. Subsequent full-scale tests confirmed this and also showed that the pickling time was not increased. These results refute the generally accepted theory that ferrous sulphate has a bad effect upon the process of pickling.

Pickling of Strip Sheet from the Metallurgical Point of View. H. P. Munger. (Iron and Steel Engineer, 1939, vol. 16, Feb., pp. 58–66). After studying the composition of scale on steel sheets and strip and discussing the theory of the action of acid upon it in the pickling bath, the author considers in detail the equipment used in the process of pickling coils of strip. He describes first a rotary type of pickler. In this the acid and the cold and hot rinsing tanks are placed round a mast which carries lifting equipment which serves all three tanks. The loose coils of strip rest on a mandrel which is lowered into the bath and rotated by a chain drive, at the same time the acid is circulated by a motor-driven propeller so as to pass through the rotating coil of strip. He then describes an in-line layout for a strip pickling plant, giving details of a scale breaking machine in which the strip is uncoiled and pulled round two small-diameter rolls, one bending it in one direction, the second reversing the bending action. He concludes with a summary of the advantages of the in-line pickler as compared with the rotary plant.

COATING OF METALS

Silver's Rôle in Industry. A. Bregman. (Iron Age, 1939, vol. 143, Mar. 23, pp. 40–41). The author gives a brief account of the research work in progress in America with a view to increasing the industrial applications of silver. He notes the increased use of silver-plated steel sheet for containers for foods, pharmaceutical products and certain oils.

Six-Stage Bonderizing Installation. N. B. Morrish. (Industrial Heating, 1939, vol. 6, Mar., pp. 246–250). The author describes an installation used for bonderising miscellaneous parts and accessories at an automobile body works. This installation is in six units for carrying out the process in six stages, namely, hot alkali washing, hot water rinsing, spraying the bonderite, cold water rinsing, chromic acid rinsing, and oven drying.

Tin Plate Production at the Tennessee Coal, Iron and Railroad Co. T. J. Ess. (Iron and Steel Engineer, 1939, vol. 16, Mar., pp. 2 T–23 T). The author presents a detailed description with numerous photographs, tables and a diagram of the layout of the new tinplate mill of the Tennessee Coal, Iron and Railroad Co. at Fairfield, Tennessee.

What is the Area of Basis Metal Exposed at Pore Sites? W. E. Hoare. (Sheet Metal Industries, 1939, vol. 13, Mar., pp. 371–373). The author explains a method of calculating the area of the base metal exposed at the sites of pores in connection with porosity tests on tinplates. (*See* Journ. I. and S.I., 1939, No. I., p. 292 A).

The Spraying of Aluminium. W. E. Ballard. (Metallurgia, 1939, vol. 19, Feb., pp. 139–141). The author describes a pistol used for spraying aluminium on to the surface of iron or steel to prevent corrosion. Aluminium wire 1–2 mm. is fed into the head and is melted at the nozzle by a coal-gas oxygen or propane-oxygen flame; the molten metal is atomised by compressed air and blown on to the surface to be treated. Under favourable conditions the pistol will spray 3–5 lb. of aluminium per hr. and at the most only 7% of the metal is lost. The author also discusses several applications of the process among which are the coating of ship's cast-iron propellers and the coating of aeroplane parts.

The Case for Electric Furnaces in the Enamelling Industry. A. G. Robiette. (Sheet Metal Industries, 1939, vol. 13, Feb., pp. 261–263). The author gives a general description of the various types of electric furnace which are suitable for the enamelling industry and discusses some of the advantages, results and operating costs obtained on typical installations. He compares continuous with batch furnaces.

Further Observations on Scientific Aids to Control in Vitreous Enamelling. G. T. O. Martin. (Foundry Trade Journal, 1939, vol. 60, Mar. 2, pp. 197–198). The author amplifies his previous paper on scientific aids to control in vitreous enamelling (*see* Journ. I. and S.I., 1939, No. I., p. 38 A), and replies to points raised in the discussion. He describes briefly two types of instrument used for measuring the thickness of enamel coatings, and explains the terms "opacity," "reflectance" (which is the quantitative expression of opacity) and "gloss." He points out that the instruments and tests he has described are not necessarily only aids to the production of better enamels, but also provide a means of classifying enamels and enamelled goods.

The Relation of Microstructure to the Enamelability of Cast Iron. G. H. Spencer-Strong. (Transactions of the American Foundrymen's Association, 1938, vol. 46, pp. 783–805). The author discusses the ability of cast iron to take enamel coatings in relation to the four most common defects which are blistering, the appearance of hairlines, poor adherence and warping, and the extent to which these defects depend upon the structure of the iron. He finds that iron containing very coarse graphite, especially if associated with very fine graphite at the surface of the casting, is more prone to blister than iron containing uniformly distributed graphite of moderate or rather fine size. He is also of the opinion that a fine pearlite structure is less likely to cause blistering than a coarse lamellar pearlite and that the adherence of an enamel coating on a chilled casting is not good.

Some Impressions of American Enamelling Practice. J. H. Gray. (Institute of Vitreous Enamellers: Foundry Trade Journal, 1939, vol. 60, Apr. 6, pp. 290–292). The author summarises the impressions received during the visit in October, 1938, of the members of the Institute of Vitreous Enamellers to many enamelling plants in the United States. He is of the opinion that, whilst stamped signs, table tops and other sheet metal work is superior in general design to those manufactured in Great Britain, the enamel finish is on the whole no better and is in several cases below the usual British standard. He notes that most American enamellers can obtain gas for heating which has a calorific value of 950 B.Th.U. for which they pay only 1*s.* 8*d.* per 1000 cu. ft., also that most works used sulphuric acid for pickling which is much cheaper than hydrochloric acid.

Thermal Expansion Characteristics of Some Ground-Coat Enamel Frits. W. N. Harrison, B. J. Sweo and S. M. Shelton. (Journal of Research of the National Bureau of Standards, 1939, vol. 22, Feb., pp. 127–136). The authors report on their investigation of the expansion of eleven different ground-coat frits suitable for sheet iron, the expansion properties of which were determined with an interferometer and a quartz tube apparatus with a dial indicator. They reproduce heating and cooling curves in which the linear

expansion is plotted against the temperature; these show the position of the critical points between 400° and 500° C. In a mathematical study they determine constants which, when substituted in simple first-order equations, permit the computation of the expansion of each frit at any temperature or temperature interval between 25° C. and the critical temperature.

"Fish-Scales" in Enamel Ground Coats. J. Klärding. (Stahl und Eisen, 1939, vol. 59, Mar. 2, pp. 268–271). The author, after describing and illustrating the shape and size of the marks like fish-scales which occur in the enamel coating on steel sheet, discusses the relationship between the temperature of stoving and the viscosity of the enamel to the tendency to the formation of this defect. He shows by means of temperature-viscosity curves the permissible stoving temperatures for enamels of different compositions. The results of tests with enamel coats of different strength showed that there was no relationship between the strength and the tendency to form fish-scales.

Base Metal Coloring. C. B. F. Young. (Steel, 1939, vol. 104, Mar. 13, pp. 60–62; Mar. 27, pp. 46–48). In the first part of this paper the author deals with the colouring of non-ferrous metals. In the second part he describes a number of processes for producing different colours on iron and steel surfaces giving the chemical composition of the solutions used.

Colored Stainless Steel. T. W. Lippert. (Iron Age, 1939, vol. 143, Apr. 6, pp. 39–45, 79–80). The author considers the possibilities of an expanding market for decorative and other articles made of coloured stainless steel. He refers to some of the patents which have been granted for colouring processes and gives some brief particulars of the Coloron process developed by the Allegheny–Ludlum Steel Corporation and the Bachite process of Oscar Bach. He also presents tables of corrosion-test data which enable the corrosion-resistance properties of untreated stainless steels and stainless steels treated by the Bachite process to be compared.

Anti-Corrosive Paints—Red Lead. A. H. Stuart. (Paint, 1939, vol. 9, Jan., pp. 16–17, 19). The author describes some experiments by which he tested the corrosion-resistance properties of red lead mixed with boiled linseed oil and applied to a polished steel rod, and discusses the effects of additions of zinc dust, graphite, and red oxide of iron to red lead priming paint.

Anti-Corrosive Paints. A. H. Stuart. (Paint, 1939, vol. 9, Mar., pp. 86–87, 89). The author considers the anti-corrosive properties of aluminium and lead pigments in paint when applied to steel erections.

PROPERTIES AND TESTS

Relation of the Stretching Speed to the Yield Point and to the other Mechanical Properties of Mild Steel. Y. Nakagawa and Z. Hasimoto. (Transactions of the Society of Mechanical Engineers Japan, 1939, vol. 5, Feb., pp. 5–11). (In Japanese). The authors investigate the effect of the rate of elongation in high-speed tension tests on mild steel with particular reference to the yield point, percentage elongation, degree of work-hardening and stress in the plastic region. They used a testing machine of their own design and obtained films of stress-time diagrams by means of a rotating camera. The elongation rates investigated ranged from 0·35% to 4·2% per sec. of the 40 mm. long test-pieces.

A New Method of Bend Testing. H. Güth. (Metallwirtschaft, 1939, vol. 18, Mar. 3, pp. 188–190). The author describes a machine for testing the bending properties of sheet metal. This method of testing has the advantage that the radius of the bend varies over a known range on a single test-piece. The machine is a press in which the lower die has a groove right across it, the shape of one end of the groove is a sharp right-angle and the radius of the bottom of the groove increases from 0 at this end to a suitable radius determined by the class of material to be tested. The upper die is V-shaped and fits its counterpart exactly. Before commencing a test the upper die is moved horizontally to a position such that the radius of the groove in the lower die at the point where the sharp end descends is equal to the thickness of the material being tested. It will be seen that when a test-piece pressed in this machine fractures along part of its length, the radius at the point where fracture begins can be determined with great accuracy.

Universal Fatigue Tester. F. Buckingham. (Steel, 1939, vol. 104, Apr. 3, pp. 38–40). The author describes a testing machine used by the Ford Motor Co. for the fatigue testing of both individual parts and large assemblies. A special mechanism enables the stroke to be maintained constant until failure occurs, or the stroke can be automatically increased to maintain the load constant until failure of the part.

On the Fatigue of Metals and its Internal Friction. Y. Kidani. (Transactions of the Society of Mechanical Engineers Japan, 1939, vol. 5, Feb., pp. 36–41). (In Japanese). The author describes his investigation of the fatigue strength of specimens of steel containing carbon 0·6%, 0·3% and 0·1% by the application of alternating torsional stresses.

Influence of the Shape of Specimen, the Testing Machine and Test Procedure on the Fatigue Strength. M. Hempel. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21,

No. 1, pp. 21–26). The author reviews the literature and describes some experiments made to determine the influence of specimen shape, type of machine and test procedure on the relationship between the tensile strength and the fatigue strength of steel specimens.

The Effect of the Type of Stress on the Fatigue Strength of Drilled and of Notched Steel Test-Pieces. F. Körber and M. Hempel. (Archiv für das Eisenhüttenwesen, 1939, vol. 12, Mar., pp. 433–444: Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 1, pp. 1–19). The authors report the results of fatigue tensile, compression, bend and torsion tests by the Wöhler method on plain, drilled and notched specimens of eight unalloyed and six chromium-nickel steels. They present the results in numerous tables and graphs. Their general conclusions are: (1) The fatigue strength of all the specimens depended more than anything else on their tensile strength; (2) even very shallow notches and minute holes lowered the fatigue strength very markedly; (3) the notch index rose with increasing tensile strength (the notch index is the ratio of the fatigue strength of a specimen with an ideal surface to that of a specimen in which there are changes of section and stress concentrations); and (4) the curves for the mean notch indices obtained from tensile, compressive and bending tests on notched and drilled specimens were very similar. The authors also carried out bending and torsional tests on notched specimens to ascertain whether changes in the angle of the V-notch had any effect on the notch index, and found that for angles between 30° and 120° the index remained unchanged. They also studied the effect of radiusing between the ends and test portions of round specimens on the fatigue strength and on the notch index. In conclusion they examine the theoretical aspect of the results obtained.

The Effect of Case-Hardening on the Bend and Torsional Fatigue Strength of Plain and Drilled Specimens. H. Wiegand and R. Scheinost. (Archiv für das Eisenhüttenwesen, 1939, vol. 12, Mar., pp. 445–448). It is generally known that in some cases the fatigue strength of certain motor-car parts is improved by case-hardening. In this investigation the authors study the effect of case-hardening the wall of a hole on the fatigue strength of a drilled specimen. The specimens tested were 14 mm. dia. and contained carbon 0·13%, chromium 2%, nickel 2% and molybdenum 0·25%. They find that case-hardening the wall of the hole improved the fatigue strength, and that the highest fatigue strength is obtained by grinding a 0·4-mm. depth of case down to 0·2 mm. They consider that when surface-finishing a case-hardened part it is not necessary to take such great care as in the case of a high-quality tempered steel.

Preparation of Rotating Beam Fatigue Specimens. Q. Henderson and W. B. Seens. (Metals and Alloys, 1939, vol. 10, Mar., pp. 82–

84). The authors describe and illustrate the equipment and procedure developed by the United States Steel Corporation for the machining and polishing of specimens for fatigue-testing in the R. R. Moore rotating-beam testing machine.

The Damping of Wires. H. Lüttgerding. (Mitteilungen des Wöhler-Instituts, 1939, No. 35, pp. 7–54). The author describes the development of a torsional oscillation machine for determining the damping capacity of 2 mm.-dia. wire. He tests its sensitivity and applicability by using it for materials with very different properties, and presents the results of tests on drawn and annealed steel wires.

Estimation of Hardenability of Steel from its Analysis and Grain Size. R. S. Archer. (Metal Progress, 1939, vol. 35, Mar., pp. 257–263, 278). The author discusses the papers read at the American Society for Metal's Symposium on Hardenability at Detroit in 1938. He shows that the hardenability of hypo-eutectoid, basic open-hearth, carbon steel made with the usual additions of silicon and aluminium for deoxidation and grain refinement, when normalised and hardened at customary temperatures, can be predicted from the chemical analysis with sufficient accuracy for all ordinary purposes. Uncertainty exists, however, in the case of steel which the McQuaid–Ehn test at 1700° F. shows to be coarse-grained because such steels may be fine-grained when quenched from some lower temperature.

The Changes in Iron and Steel at Atmospheric Temperatures. J. H. Andrew. (Journal of the West of Scotland Iron and Steel Institute, 1938, vol. 46, Dec., pp. 51–59). The author discusses the phenomenon and causes of the hardening of steel which takes place in the cold state following upon a process of rapid cooling or after cold working. If the material has been quenched the phenomenon is known as "quench-ageing"; if it has been cold worked it is called "strain-ageing." He shows that the difference between the final cold-worked hardness of electrolytic iron and carbon steel must be due to the carbon in the latter, and the only possible explanation is that the carbon goes into solution in the iron forming austenite which, immediately following its formation, will transform to hard martensite. Whether the cold-work be imposed by wire drawing, rolling or by tensile stress, the effect is inevitably the same. He quotes the work of a number of investigators and deduces from their observations of tensile tests that, the moment the straight line part of the load-extension curve is passed, the plastic flow which follows is continually producing a change in the constitution of the materials.

High-Carbon Iron-Aluminium Alloys with Increased Coercive Force. B. Somin and D. Leykina. (Stal, 1938, No. 7, pp. 57–62). (In Russian). It was already known that a high coercive force (up to 200 oersted) could be obtained in alloys containing 6–8% of aluminium and 2–2·5% of carbon. The authors now report on an investigation of the effect of different rates of cooling

and different subsequent heat treatments on the magnetic properties and structure of these alloys. They find that in the martensitic state the alloys have a maximum coercive force of 180–200 oersted and a maximum hardness of 60–65 Rockwell C units, and in the precipitation-hardened state these figures are 140–150 and 55 respectively. They produce the martensitic state by direct quenching from high temperatures or by tempering the alloy in the quenched austenitic state at 300° C. They produce the precipitation-hardened state by tempering the quenched alloy at 500° C.

A Magnetic Process of Testing the Temper-Condition of Finished Steel Parts. H. Lange. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 6, pp. 105–113). The author describes the Siemens–Halske ferrometer which, when used in conjunction with a co-ordinate recorder, enables hysteresis curves for steel specimens magnetised by an alternating current to be obtained. (The co-ordinate recorder is a highly sensitive moving-coil mirror galvanometer recording two ordinates at 90°). This apparatus is applied to determine the hardness properties of steel by simultaneously magnetising the piece to be tested and a piece of known good quality and measuring the difference in inductive capacity of the two pieces under equal excitation. The author found that the hardness properties could be determined by using weak magnetic fields. He also describes a simple apparatus for controlling the hardness of heat-treated and quenched tools.

Alternating Hysteresis Loss in Electrical Sheet Steels. F. Brailsford. (Journal of the Institution of Electrical Engineers, 1939, vol. 84, Mar., pp. 399–407). The author describes a direct method of measuring alternating hysteresis loss in sheet materials using small disc specimens. The loss may be measured in any desired direction in the sheet on the same samples, utilising simple apparatus and no eddy-current losses are involved in the measurement. He presents the results from specimens of four electrical sheet materials. He finds that the Steinmetz law holds approximately for the lower portion of the loss curves, and a straight-line law for the upper portion. The change is found to occur near the knee of the magnetisation curve where, according to theory, the mechanism of the magnetisation process also changes. He finds that there is a definite relationship between the loss and magnetisation curves for different sections in the sheet, and concludes that hysteresis loss is a function not only of the magnetisation but also of the field strength. From observations on one of the samples he infers the general relation of alternating hysteresis loss in a single crystal of silicon iron to the principal crystal directions. He compares the alternating with rotational hysteresis loss and finds that the ratio between them is approximately the same for all the four materials investigated.

Effects of Niobium and other Addition Agents on Low-Chromium Steels. R. Franks. (Transactions of the American Society for Metals,

1939, vol. 27, Mar., pp. 78–104). It has been found that steels containing 4–6% of chromium when used in plant operating at 400–650° C. became brittle especially when the plant was shut down for long periods during the winter. In this paper the author describes an investigation of the effect of alloy additions on low-chromium steel with a view to overcoming this defect. It was found that adding niobium to the extent of 6–10 times the amount of carbon in the steel effectively reduced the tendency to air-hardening, improved the resistance to oxidation at temperatures up to 700–750° C. and did not detrimentally affect the creep strength at 538° and 594° C. Additions of molybdenum as well as niobium increased the creep-resistance of these chromium steels, whilst additions of titanium or vanadium without niobium reduced the air-hardening tendency, but such steels did not retain their toughness as did those containing niobium.

The Effect of Molybdenum in Carbon Steel in Comparison with that of other Carbide-Forming Elements. E. Houdremont and H. Schrader. (Technische Mitteilungen Krupp, Forschungsberichte, 1939, vol. 2, Mar., pp. 23–46). The authors discuss the results of investigations of the effect of molybdenum upon the structure, hardenability, and cutting properties of carbon steels. They show that with steels containing 0·15%, 0·35% and 0·9% of carbon and additions of up to 6% of molybdenum with the low carbon and up to 16% with the high carbon, the carbon increases the retardation of the transformation phenomenon and the molybdenum increases the depth of hardness to an extent which greatly exceeds the similar effect of chromium additions to eutectoid tool steels. From this they conclude that carbides are formed which are comparatively easily soluble. A nucleus effect of the undissolved carbides is observed up to high temperatures and this limits the sensitivity to excessive heating in the hardening process. The frequently observed needle structure in molybdenum steels is caused by the retarded transformation. This is similar to the well-known Widmannstätten structure, and like it, it may be regarded as an intermediate structure the formation of which is dependent upon the annealing temperature and the cooling conditions. The basis of the formation of this structure in the course of ordinary heat treatment is that the steel contains alloying elements such as nickel and chromium which suppress the transformation.

The abnormal structure of steels alloyed with molybdenum only cannot be satisfactorily explained by a high Ar_1 transformation point or by an unusual diffusion and balling-up tendency of the carbon. The increased surface decarburisation of molybdenum steels and the deeper penetration of scale are due to the increased penetration of oxidising gases or the increased solubility of oxide particles, whilst the approximately uniform width of the hypo-eutectoid zone which corresponds to the carbon migration during cementation is not evidence of an important change in the rate of

carbon diffusion. The annealing of molybdenum steels tends to produce irregularities of structure for, although the carbide occurs mostly in fine grains, a balling-up of carbide also occurs here and there. The probable explanation of this abnormal structure in molybdenum steels is that a disintegration of the austenite takes place, the theoretical causes of which are the increased pressure due to carbide formation and the decreased solution pressure.

The effect of an addition causing the formation of a special carbide corresponds to the increased hardenability and heat-resisting properties of molybdenum steels and an addition of molybdenum therefore increases the cutting properties. The life of a water-quenched tool of molybdenum steel is longer than that of an oil-quenched one because there is more austenite in the latter. The authors find that by adding chromium and vanadium to a 3%-molybdenum steel it is possible to obtain a high-speed steel with a life and cutting properties equal to those of steel containing tungsten 14%, chromium 4% and vanadium 2·5%.

Molybdenum in Cast Iron. W. F. Chubb. (Foundry Trade Journal, 1939, vol. 60, Mar. 30, pp. 274–277). The author presents and discusses data which show the improvement likely to be obtained when molybdenum is added to various types of iron. The benefits to be derived from the addition of molybdenum to grey iron are, however, not solely dependent upon the molybdenum, but are dependent upon the presence of other elements. Thus, the tendency to increase in hardness is least when chromium is present and greatest when nickel is present. The tendency towards increased transverse strength is greatest in the nickel-molybdenum combination, but the highest increases in tensile strength are reported to occur in the chromium-molybdenum cast irons.

Alloy Cast Iron. A. J. N. Smith. (Journal of the West of Scotland Iron and Steel Institute, 1938, vol. 46, Nov., pp. 39–45). After reviewing some of the general effects common to all alloy additions to cast iron, the author discusses the particular effects of additions of nickel, chromium, molybdenum, copper and aluminium. He concludes with some observations of the technique employed when adding the alloying element.

Alloy Cast Iron. H. A. MacColl. (Foundry Trade Journal, 1939, vol. 60, Mar. 2, pp. 189–190; Mar. 9, pp. 219–220; Mar. 16, pp. 235–236; Mar. 23, pp. 256–257). In the first part of his paper the author considers the criticisms levelled against cast iron as an engineering material and explains the appearance and characteristics of the primary constituents graphite, ferrite, pearlite, phosphide eutectic and cementite. He then explains that high-duty cast iron can be produced by (*a*) improving the properties of the matrix and/or controlling the quantity, size and distribution of the graphite flakes, and (*b*) developing irons with new structural constituents possessing enhanced properties. The technique by which this is achieved is either the introduction of alloying elements, or super-

heating, or the process of inoculation. In the second part the author shows the effects of reducing the silicon content with and without additions of nickel on the strength, hardness and chill properties of cast iron. He then considers the influence of chromium and chromium-nickel additions. The author devotes the third part to considering the effects of additions of molybdenum, vanadium and copper on the mechanical properties of cast iron. He concludes this part with some notes on heat-resisting irons with special reference to " Silal " which contains 4–10% of silicon and the carbon almost wholly as graphite in a very finely divided state. In the fourth part the author discusses the nickel-irons known as " Ni-hard," " Nicrosilal," " Ni-resist " and " Ni-tensyl," the last-named being an example of an inoculated iron. He stresses the fact that success with alloy irons is dependent on ability to produce ordinary irons of the highest class. He concludes by describing the technique employed for adding the alloying elements to the iron.

High-Duty Cast Irons for General Engineering Purposes. (First Report of the Research Committee of the Institution of Mechanical Engineers, Dec. 16, 1938: Foundry Trade Journal, 1938, vol. 59, Dec. 22, pp. 459–462; Dec. 29, pp. 483–484, 492). In 1936 an exploratory committee of the Institution of Mechanical Engineers was appointed and as a result of their work the Institution formed a research committee " to make a systematic and co-ordinated exploration of the properties and performance of high-duty cast irons, with special reference to their development and use for general engineering purposes." The first report of this committee is reproduced in this series of articles. In it recent developments in high-duty cast irons are reviewed under the following sections: the use of refined pig iron and steel in charges, hot-mould iron, alloy cast irons, melting practice, inoculated irons, heat treatment, malleable cast irons, low-carbon alloy irons and special irons. The physical and mechanical properties are also discussed in this part.

Investigations of the Present Position of the Mechanical Properties of Malleable Cast Iron. H. Dittmar. (Giesserei, 1939, vol. 26, Mar. 24, pp. 137–145). The author presents a report on the investigations carried out by the Malleable Cast Iron Technical Committee of the Verein deutscher Giessereifachleute. This work was undertaken because it was considered that DIN 1692 (German Engineering Standard) for malleable cast iron was out of date, and this report contains proposals for standardising the mechanical properties of this class of iron. The committee considers that the test-pieces used should have a length equal to three times the diameter, not five times the diameter as formerly. The author reproduces several graphs showing the elongation in relation to the tensile strength for a number of whiteheart and blackheart malleable cast irons.

Physico-Technical Properties of Fechral from the Point of View of its Applications. V. Erakhtin and V. Prozorov. (Stal, 1938, No. 7, pp. 62–66). (In Russian). The authors study the structure,

electrical resistance, resistance to scaling and creep-resistance of three heats of "Fechral" alloy steel which contains carbon 0·14–0·20%, manganese 0·51–0·73%, silicon 0·47–1·06%, chromium 12·0–13·1% and aluminium 3·1–4·8%, and consider the application of Fechral wire for making electrical resistance heating elements.

On the Strength Properties of Cast Steel from a High Frequency Acid Furnace as Compared with that made by Other Processes. H. Heinrich. (Breslau Technische Hochschule, Dissertation, 1938). The author presents an account of an investigation in which he compared the properties of unalloyed and low-alloy cast steel made by different processes, namely, in an H.F. acid furnace, in an open-hearth furnace and in a small Bessemer converter. The specimens tested were all annealed and some were oil-quenched. Tensile tests produced approximately equal results. Notched-bar impact tests on annealed specimens also produced similar results except that in some cases the Bessemer steel showed brittleness which was found to be due to phosphide precipitation, but impact tests on quenched specimens showed markedly differing results, the steel from the H.F. furnace having the highest impact strength and the Bessemer steel the lowest. The actual test results are given in tables, which together with graphs and micrographs, form an appendix of 42 pages.

The Effect of the Deoxidation of Steel on its Mechanical Properties, particularly in the Hot State. H. Buchholtz. (Stahl und Eisen, 1939, vol. 59, Mar. 16, pp. 331–338). The author discusses and compares the effects of deoxidising steel with aluminium and with ferro-silicon upon the grain size, sensitivity to tempering, notched-bar impact strength at high temperatures and the creep limit. He finds that course-grained steels deoxidised with ferro-silicon have a much higher creep limit than fine-grained steels deoxidised with aluminium when both kinds have the same chemical composition and have been subjected to similar heat treatment.

Strength of Marine Engine Shafting. S. F. Dorey. (North-East Coast Institution of Engineers and Shipbuilders, Mar. 24, 1939). The author explains in detail the results of investigations of the strength of marine-engine shafting which have been made by measuring and calculating torsional and axial vibration, alignment and rough-weather stresses, as well as by the examination of actual fractures in service.

High-Speed Steel RF2 with increased Carbon Content. D. Zhitnikov. (Stal, 1938, No. 7, pp. 73–75). (In Russian). The author studied specimens of steels *RF*1 and *RF*2, the analyses of which are carbon 0·57% and 0·95%, chromium 4·49% and 4·16%, tungsten 18·06% and 12·58%, and vanadium 1% and 2·6% respectively; the manganese is about 0·21%, and 0·95% of carbon in steel *RF*2 is about 0·2% higher than the usual amount in this steel. He reports briefly the results of metallographic and magnetometric examinations and on the hardness and cutting properties. He

finds that steel *RF*2 has excellent cutting properties, and the best heat treatment consisted of quenching from 1300° C. and tempering at 560–580° C. With the proper heat treatment this steel has a permanent hardness of 63–65 on the Rockwell C scale.

British Standard Specification for Mild Steel Shackles for Lifting Purposes. (British Standards Institution, No. 825, 1939).

Here is a Laboratory which Includes a Complete Steel Plant. (Sheet Metal Industries, 1939, vol. 13, Apr., pp. 485–486). An illustrated description is given of the research and development laboratory of the Jones and Laughlin Steel Corporation of Pittsburgh which contains a miniature steel plant and rolling mill. (*See* Journ. I. and S.I., 1939, No. I., p. 41 A).

METALLOGRAPHY AND CONSTITUTION

A Scale for Deep-Etching Tests for Steel Bars with a High-Carbon Content. R. Arpi, H. Kjerrman and G. Thalén. (Jernkontorets Annaler, 1938, vol. 122, No. 11, pp. 581–591). (In Swedish). The authors describe a scale for estimating the degree of central pitting in deep-etched sections of high-carbon steel. The scale consists of five macrographs designed to show different degrees of pitting, increasing from No. 1 to No. 5. They describe the preparation of the specimen and of the hydrochloric acid etching solution and the test procedure. The scale and method described are based on earlier work of a committee appointed by the American Society for Metals and by H. G. Keshian and on special investigations by B. Wesslén. (*See* following abstract).

An Investigation of the Conditions Necessary for Obtaining Uniform Results in Deep-Etch Testing. B. Wesslén. (Jernkontorets Annaler, 1938, vol. 122, No. 11, pp. 592–608). (In Swedish). Under the supervision of a committee on deep-etch testing appointed by the Board of Research of Jernkontoret the author has investigated the influences of various factors on the results of deep-etch tests. He found that : (1) The original position of the test specimen in the ingot has a marked effect on the result of the deep-etch test ; (2) the influence of the surface treatment of the specimen is unimportant ; (3) $FeCl_3$ in the etching solution considerably increases the amount of metal etched away, whereas $FeCl_2$ and $PbCl_2$ have the opposite effect. All these compounds slightly improve the grade number (*see* preceding abstract) ; (4) a high proportion of arsenic in the etching acid gives the etched surface a very irregular appearance ; (5) the acid concentration must be kept as near constant as possible ; (6) an increase in the bath temperature from 70° to 80° C. increases the grade number by about half a unit in such cases where distinct etching pits occur ; and (7) an etching time of 45 min. at 70° C. is sufficient for unalloyed hard carbon steels.

A Magnetic Method of Detecting Surface Defects in Magnetic Irons. I. Feszczenko-Czopiwski and L. Kozlowski. (Prace Badawcze Huty Baildon, 1938, Dec., No. 4, pp. 25–29). (In Polish).

A Magnetic Method of Determining the Degree of Decarburisation of Austenitic Manganese Steels. T. Zarański and St. Kuliński. (Prace Badawcze Huty Baildon, 1938, Dec., No. 4, pp. 47–59). (In Polish).

Influence of Atmosphere and Pressure on Structure of Iron-Carbon-Silicon Alloys. A Boyles. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1046 : Metals Technology, 1939, vol. 6, Apr.). The author describes the

apparatus used for melting iron-carbon-silicon alloys containing carbon 3·03–3·21% and silicon 0·47–1·23% in an atmosphere of hydrogen at pressures from a partial vacuum up to 300 lb. per sq. in. He also discusses the effect of the hydrogen and of different cooling rates upon the structure of the alloy. He finds that: (1) Hydrogen stabilises the eutectic carbide in these alloys when the sulphur and manganese contents are very low. The effect diminishes as the silicon content is increased; and (2) melting under pressure in hydrogen increases this stabilising effect.

Mechanism of Eutectic Crystallisation of White Cast Iron. K. Bunin and S. Rapoport. (Metallurg, 1938, No. 11, pp. 29–33). (In Russian). Using cast iron containing carbon 3·6%, silicon 0·36% and manganese 1·7%, the authors study the effect of different rates of cooling (20°, 30° and 168° C. per min.) on the process of eutectic crystallisation. Cooling at the above rates was interrupted at different stages by quenching and the structure of the specimens obtained was examined microscopically. In general the results obtained agree very well with the general theory of eutectic crystallisation put forward by Bochvar. The eutectic crystallisation process in white cast iron starts with the independent separation of phases entering into the composition of the eutectic, thus explaining the anomalous structures frequently encountered. Subsequent progress of the eutectic crystallisation is entirely dependent on the rate of cooling. Slow cooling results in a coarse austenite-cementite structure, devoid of the characteristics of a eutectic. The structure of ledeburite, which is formed as a result of sufficiently rapid cooling, crystallises in what is essentially a spheroid form. The eutectic forms round a cementite grain, the crystals of austenite and cementite forming the eutectic being arranged radially. In conclusion the authors refer to some additional investigations of mottled cast iron. These investigations show that the grey constituent of the mottled cast iron is formed before the white constituent. This evidence supports the theory of the direct crystallisation of graphite from solution in the melt.

What About Grain Size? C. L. Shapiro. (Iron Age, 1939, vol. 143, Mar. 16, pp. 25–27; Mar. 30, pp. 23–27; Apr. 6, pp. 33–37). In Part I. of this series the author describes three test procedures for determining the austenitic grain size in steel, these are: (1) Etching at room temperature to reveal the austenitic grain size that existed prior to cooling; (2) etching at elevated temperatures and observing the structural condition that existed at this temperature by microscopic examination at room temperature; and (3) examination of fracture at room temperature. In Part II. he considers the factors which influence the size of the austenite grains and in Part III. he deals with the effects produced by different grain sizes upon the mechanical and physical properties of steel.

The Capillarity of Metal Grains: Its Influence on their Growth and Its Importance in Steel. C. Benedicks. (XVIII^{e} Congrès de

Chimie Industrielle, Sept.–Oct., 1938 : Chimie et Industrie, 1939, vol. 41, Mar., pp. 434–446). **Concerning the "Body" of Steel.** C. Benedicks. (Blad för Bergshandteringens Vänner, 1938, No. 1). The author describes and explains two classes of grains in metals which he calls "accidental" and "capillary." The former are those which grow from centres situated at random in the metal; their boundaries form flat surfaces and the angles between the surfaces vary considerably. The latter are those influenced by capillary attraction; these have a tendency to change position, their boundaries are curved, their surface area is small, and the angles between the boundaries are approximately equal (about 120°). He considers the effect of capillary attraction upon grain growth and the adsorption properties. He then discusses at some length the thermal stability of steel and the addition of alloying elements such as manganese, titanium, zirconium and vanadium, which by assisting the formation of nitrides, increase the thermal stability of steel. In conclusion he explains the term "body" as applied to steel and the dependence of "body" on good mechanical properties, high thermal stability and low decarburisation tendency.

On the Brittleness, Plasticity and Slip Elements of α-Iron and the Condition of the Slip Planes. H. G. Sossinka. (Breslau Technische Hochschule, Dissertation). In the first part of his paper the author describes his investigation of the brittleness, plasticity and twinning of single crystals of α-iron at temperatures down to − 136° C. He finds that under tensile stress and at low temperatures a mechanical process of twinning of α-iron single crystals occurs with {112} as the twinning plane and that at room temperature and under compressive stresses the transformation plane of α-iron is at {123}. In the second part of his paper he presents a mathematical study of the twinning of cubic face- and body-centered lattices under conditions of simple displacement.

On the Austenite Precipitation in a Vanadium Steel in the Supercooled Condition; the Relationship of the Rate of Precipitation and the Structure on the Pretreatment and the Precipitation Temperature. F. Wever and H. Lange. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 3, pp. 57–64). The authors report on an investigation, using a magnetic balance, of the precipitation of austenite in a steel containing vanadium 1·02% and carbon 0·78% in the supercooled state. They found that the transformation occurred in three stages. In the first, from 700° to 540° C. a pearlitic-troostitic structure was formed; in the second, from 540° to about 350° C. the structure consisted of groups of parallel needles; and the third corresponded to a martensitic structure.

On the Relationship between the Equilibrium Diagrams of Binary Iron Alloys in the Peritectic Transformation Range. B. N. Svetchnikov. (Metallurg, 1938, No. 11, pp. 17–22). (In Russian). After examining the data obtained by previous investigators of the binary systems Fe–Co, Fe–Cu, Fe–C, Fe–Au, Fe–B, Fe–Zr, Fe–Ni and

Fe–Mn, the author finds that these can be classified into two groups distinguished by the relative solubility of the alloying element in δ-iron and γ-iron at the temperature of the peritectic transformation. In the first group the solubility of the alloying element is greater in γ-iron than in δ-iron, the reverse being true for the second group. The author subdivides the first group into two parts depending upon whether the solutions are of the "substitutional" or "interstitial type." In conclusion he presents a calculation of the densities of the γ- and δ-phases of the iron-nickel alloys at the peritectic temperature which shows that their densities are the same.

The Iron-Nickel-Chromium Equilibrium Diagram with Special Reference to the Brittle Structures which Form after Long-Time Annealing. P. Schafmeister and R. Ergang. (Archiv für das Eisenhüttenwesen, 1939, vol. 12, Mar., pp. 459–464). This paper appeared in Technische Mitteilungen Krupp, Forschungsberichte, 1939, vol. 2, Feb., pp. 5–14. (*See* Journ. I. and S.I., 1939, No. I., p. 307 A).

The Brittle σ-Phase in the Fe–Cr–Mn Constitutional Diagram. P. Schafmeister and R. Ergang. (Technische Mitteilungen Krupp, Forschungsberichte, 1939, vol. 2, Mar., pp. 15–21 : Archiv für das Eisenhüttenwesen, 1939, vol. 12, Apr., pp. 507–510). The authors determine the stable portion of the brittle, hard and non-magnetic σ-phase of the iron-chromium-manganese constitutional diagram up to 50% of manganese and 90% of chromium. The σ-portion can dissolve up to 35% of manganese, and is present even up to 64% of manganese. Four single-phase, five two-phase and two three-phase planes appeared in the isothermal section as developed by the authors at 700° C. The σ-phase reverted to ferrite between 800° and 1000° C. on heating. They compare this diagram with that of the iron-chromium-nickel system ; in the latter the σ-phase only dissolves about 10% of nickel and does not appear when the nickel content exceeds 33%.

An X-Ray Study of the Iron-Palladium and Nickel-Palladium Systems. R. Hultgren and C. A. Zapffe. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1047 : Metals Technology, 1939, vol. 6, Apr.). The authors report on their X-ray examination of iron-palladium and nickel-palladium alloys. The Debye patterns of iron alloys containing 5·5, 10 and 20 atomic-% of palladium showed a well defined two-phase region at temperatures below 750° C. The same samples quenched from 800° C. gave quite different results, for diffraction lines of a single body-centred cubic lattice appeared in the Debye patterns. The lattice constants of this phase increased practically linearly with the palladium content, indicating that the palladium was dissolved. The expansion of the lattice was about twice as great as that predicted by Vegard's law.

The System FeO–TiO_2. J. Grieve and J. White. (Journal of the Royal Technical College, 1939, vol. 4, Jan., pp. 441–448). The

authors determined the thermal equilibrium diagram of the FeO–TiO_2 system by a thermal analysis and microscopic examination of representative mixtures. Two compounds $2FeO.TiO_2$ (pseudo-brookite) and $FeO.TiO_2$ (ilmenite) are formed between the components, and there are three eutectic points. X-ray powder photographs confirm the formation of two crystalline compounds and indicate that TiO_2 crystallises from the melts as rutile.

High Temperature Melting with an Electron Bombardment Furnace. R. Hultgren. (Industrial Heating, 1939, vol. 6, Mar., pp. 203–206). The author describes briefly an electron bombardment furnace recently constructed at the Harvard University Laboratory of Physical Metallurgy. In this furnace a filament placed near a crucible of conducting material is electrically heated and the unit is in a chamber in which a high degree of vacuum is maintained by a high-speed oil diffusion pump. Electrons from the filament bombard the crucible shell, liberating their energy mainly in the form of heat. Temperatures up to 2850° C. have been obtained, and in one instance a tantalum shell was melted using only 700 watts. This furnace is to be used for preparing specimens of alloys containing such metals as titanium, vanadium, zirconium, columbium and platinum in order to study equilibrium diagrams.

The Inverse-Rate Curves of Steel No. 10. F. W. Jones and C. Sykes. (Addendum to Section IX. of the Second Report of the Alloy Steels Research Committee (Iron and Steel Institute, 1939, Special Report No. 24); Journal of the Iron and Steel Institute, 1939, No. I, pp. 537P–547P). The paper describes certain experiments carried out to provide further information regarding the heat evolved during the transformation in steel No. 10, the thermal analysis and metallurgical analysis of which (with other steels) were described in Part 2 of Section IX. of the Second Report of the Alloy Steels Research Committee. It is shown that at slow rates of cooling the lower arrest observed on the inverse-rate curve at 390° C. should be interpreted as marking the end of a transformation, as predicted by Russell. A modified cooling technique is suggested which could be employed in the investigation of transformations where the interpretation of the standard inverse-rate curve is not straightforward.

CORROSION OF IRON AND STEEL

The Influence of Various Factors on Corrosion Tests. A. Portevin. (Métaux et Corrosion, 1939, vol. 14, Feb., pp. 17–29). So many different corrosion tests have been developed during recent years that the author considers it advisable to survey the factors affecting such tests with a view to eliminating those which do not satisfy the fundamental requirements. He therefore studies those factors in three separate groups, which are governed by the conditions prevailing at the beginning, during, and at the end of the test. He subdivides the three groups so that his survey covers the following eight points: (1) The surface condition of the specimen; (2) the selection of the specimen and the importance of segregation in steel; (3) the effect of scale and passivity; (4) the effect of various conditions of testing on the uniformity of the results; (5) the standardising of tests; (6) the condition of the surface at the end of the test; (7) the products of the reaction; and (8) comparison of laboratory test with behaviour in service.

Practical Problems of Corrosion. Part XI. Seven-Year Exposure Tests on Metallised and Painted Steel Specimens. S. C. Britton and U. R. Evans. (Journal of the Society of Chemical Industry, 1939, vol. 58, Mar., pp. 90–93). The authors report the results of outdoor exposure tests on specimens of steel sprayed with aluminium by the Schoop process in which specimens were exposed for seven years in London, Cambridge and Grantchester Meadows, and for four years at Selsey Bill. All these specimens showed no rusting, but some change occurred in the aluminium layer, especially in London; this change is less marked with relatively pure aluminium and is absent on specimens where a single coat of paint has been applied outside the aluminium.

Micro-Biological Experiments in Anaërobic Corrosion. H. J. Bunker. (Journal of the Society of Chemical Industry, 1939, vol. 58, Mar., pp. 93–100). The author discusses the mechanism of the corrosion of metals in anaërobic conditions, such as prevail in heavy clay soils, from the micro-biological aspect. The activity of the sulphate-reducing organisms of the type *Vibrio desulphuricans* causes the sulphate present to act as a hydrogen-acceptor and hence as a depolariser of the cathode, whilst iron sulphide is formed by the interaction of the iron dissolved at the anode with the hydrogen sulphide produced bacterially. The examination of the corrosion products and the soil surrounding attacked water mains shows the accumulation of iron sulphide in the corrosion products and relatively high numbers of sulphate-reducing bacteria in association with the damaged areas. Controlled laboratory experiments are now in

progress in which iron and steel specimens are exposed to corrosion in strictly anaërobic conditions, with and without an inoculant of *Vibrio desulphuricans*. The first experiment shows a loss in weight of the inoculated specimen nearly twenty times as great as that of the sterile specimen.

Pit Corrosion of Stainless Steel. W. W. Buffum. (Metal Progress, 1939, vol. 35, Mar., pp. 247–248, 298, 306). The author reviews the work of H. H. Uhlig and J. Wulff on the causes of pitting corrosion of stainless steel by stagnant sea water or polluted harbour water, which they carried out at the Massachusetts Institute of Technology. Their experiments revealed that stainless steel annealed under a vacuum and polished was not susceptible to pitting, but if the specimen were coarse-ground it would pit readily. They also found that pits were preferentially located at austenitic grain boundaries rather than at identifiable particles of carbide within the grains. The author also describes the experiments which led the investigators to conclude that pits are caused by ferric chloride attack concentrated at some point where the passive stainless steel surface has been converted to an active surface, and that the passive surface has to do with the distribution of electrons among the metallic atoms rather than with the creation of an impervious oxide layer.

The Present State of Knowledge of the Caustic-Embrittlement of Boiler Plates. G. T. Athavale. (Korrosion und Metallschutz, 1939, vol. 15, Mar., pp. 73–80). In surveying the literature on the caustic-embrittlement of boiler plates the author shows that the generally accepted theory for the cause of this phenomenon is that local stresses tend to separate the grains and thus facilitate the attack on the grain boundaries by any alkalies present in the boiler feed water. Some investigators, however, exclude the possibility of the action of alkaline solutions and state the cause is to be found in the action of hydrogen on impurities in the steel. It is also stated that steels containing nitrogen after cold-working and ageing are very susceptible to caustic-embrittlement. A bibliography with 98 references is appended.

Intercrystalline Cracking of Boiler Plates. C. H. Desch. (Engineer, 1939, vol. 167, Mar. 31, pp. 418–419). A reproduction of an article which appeared in Iron and Steel Industry, 1939, vol. 12, Feb., pp. 304–307. (*See* Journ. I. and S.I., 1939, No. I., p. 376 A).

Contribution to the Knowledge of the Intercrystalline Corrosion of Soft Iron in Ammonium Nitrate Solution. M. Smialowski. (Korrosion und Metallschutz, 1939, vol. 15, Mar., pp. 81–82). The author describes an investigation carried out to determine whether the corrosion of strips of soft sheet-iron in ammonium nitrate solution proceeded along the grain boundaries, or along crystallographic surfaces, or along lines where impurities were present. The results showed in the case of single crystal specimens, that there was no corrosion of the individual crystals, but corrosion cracks appeared in the specimens of polycrystalline structure and these cracks always

followed the grain boundaries without regard to the zones of maximum deformation.

The Internal Corrosion and Internal Protection of Gas Mains. A. Matting and G. Goos. (Korrosion und Metallschutz, 1939, vol. 15, Mar., pp. 83–85). The authors study the causes of the internal corrosion of gas mains with numerous references to the literature and give the general conclusions obtained from the results of tests carried out in Hamburg on the efficiency of various methods of protection. These conclusions are: (1) Burnt-on coatings are better than those applied cold; (2) the degree of attack on a coating varies at different parts of a main because of the different concentrations of moisture and other chemicals; (3) tubes made of steel plate with a chemically treated surface have excellent corrosion-resistance properties; and (4) all bituminous paints are liquefied by the town gas. In conclusion the authors mention some methods of treating town gas in order to inhibit corrosion.

Recent Developments in Pipe Protection. C. H. S. Tupholme. (Colliery Engineering, 1939, vol. 16, Mar., pp. 101–102). The author describes a method used successfully in America to combat the corrosion of buried pipe-lines.

Some Notes on Routine Corrosion Tests for Tinplate. W. E. Hoare. (Sheet Metal Industries, 1939, vol. 13, Feb., pp. 227–228; Mar., pp. 374, 376). In devising routine corrosion tests for tinplate the significant factors to be considered are the mean thickness of the coating and the variations from the mean, the characteristics of the steel base, the degree of continuity of the coating and the service value of the material. The author discusses these factors and the relationship between the porosity and the thickness of the tin coating. He also describes a routine control test for tinplate evolved in America to eliminate the small proportions of material responsible for the appearance of "hydrogen swells" after short storage time. In this test a coefficient of resistance termed the "hydrogen evolution value" is determined; this value is the time in hours required to produce 5 c.c. of gas by the action of hydrochloric acid on a die-formed specimen held in a special apparatus. This value is correlated with the "can service value" which is the time in months required for 50% of a lot of plain cans to "hydrogen-swell" when stored at 100° F.

Bibliography on Corrosion Resisting Cast Iron, with special reference to Chemical Attack. G. R. Woodward. (Bulletin of the British Cast Iron Research Association, 1939, vol. 5, Mar., pp. 344–354). The author presents a bibliography consisting of 78 references to the literature on the corrosion of cast iron. The references are selected from British, French, German and American publications and in most cases the author gives a brief summary of the paper in question, and in those instances where a translation has been published he gives a cross reference to show where it can be found. Twelve of the items refer to patents.

BOOK NOTICES

AMERICAN SOCIETY FOR TESTING MATERIALS. "*Index to the Literature on Spectrochemical Analysis* 1920–1937." By William F. Meggers and Bourdon F. Scribner. Publication Sponsored by Committee E-2 on Spectrographic Analysis of the American Society for Testing Materials. 8vo. pp. 59. Philadelphia, 1939 : The Society. (Price $1.00.)

This is the first general comprehensive index of the literature on spectrochemical analysis, and covers the period 1920–1937 inclusive. There are over 900 references arranged in chronological order and in alphabetical order of author for each year. All paper-titles are given in English, but book-titles have not been translated. Instead of printing an abstract with each paper, references to already published abstracts are given.

AMERICAN SOCIETY FOR TESTING MATERIALS. "*A.S.T.M. Specifications for Pipe and Piping Materials for High Temperature and High-Pressure Services.*" 8vo. pp. v + 128. Philadelphia, 1938 : The Society. (Price $1.25.)

For many years Committee A-1 on Steel of the American Society for Testing Materials has been developing specifications covering steel materials for high-temperature service. Quite a number of standards have been issued and published as separate pamphlets and also in the book of A.S.T.M. Standards. In order to make the specifications in this particular field available in convenient compact form, they have been issued in this brochure. Specifications are included for carbon steel and alloy steel pipe and tubing, castings, forgings and bolting for central station power plants of similar industrial installations of piping materials. Several have been approved as American Standards by the American Standards Association and a number have been adopted by the Boiler Code Committee of the American Society of Mechanical Engineers.

AMERICAN SOCIETY FOR TESTING MATERIALS. "*Index to A.S.T.M. Standards and Tentative Standards.*" 8vo. pp. 129. Philadelphia, 1939 : The Society.

This index is a compilation, under appropriate key-words, of titles and serial designations of all A.S.T.M. Standards and Tentative Standards, together with the volume references to the publications in which they appear. Each standard has been indexed under the principal subjects covered. To facilitate finding the item desired, the items under each subject have been arranged alphabetically according to the significant word in the title. Under any keyword subject, where three or more items cover related subjects, these have been grouped alphabetically and indented under the significant word or words common to the titles of the several items.

FAWCETT, J. R. "*Designing for Mass Production. An Introduction.*" 8vo. pp. ix + 141. Illustrated. London, 1939: Sir Isaac Pitman & Sons, Ltd. (Price 8*s.* 6*d.*)

This small book of one hundred and forty-one pages is intended to serve as an introduction to the subject, and its need arises from the rapid increase in the number of light mechanical articles which are now made by mass-production methods. To suit these methods of production the article must not only be mechanically sound, but it must also possess a pleasing and distinctive appearance when offered for sale to the public. These essentials have led to a completely new technique in design, thus representing a departure from traditional methods. Older text-books devoted to engineering design are for these reasons of little value in a study of modern production methods, and the author has made it his endeavour to include in this book all that must now be regarded as essential to those interested in mass production of small parts and components. The author claims to have read every available work published in America and England which relates to this subject, and in preparing the text has assumed that the reader will be familiar with ordinary workshop processes and that he has also some knowledge of machine drawing. There is thus provided a brief outline of the properties of materials, and an account of heat and mechanical treatments used in mass production, more particularly in regard to their effects upon properties. Both ferrous and non-ferrous materials are here briefly covered and, as plastics have assumed an important place in engineering design and production, an account also of phenol-formaldehyde and urea-formaldehyde synthetic resins is also included, with notes on their moulding. Among the manufacturing methods discussed is machining, such as turning, milling, broaching and grinding, although on account of the small size of the book the treatment given in each instance is very limited. In presswork, the operations of bending, raising, drawing, coining, beading, wiring, and plunging have been covered, and these chapters conclude with a short account of welding, soldering, and the surface finishing of metals, as by lacquering and rust-proofing. While these subjects will be found to be of considerable interest, it is suggested that, as far as metallurgists are concerned, more particularly those metallurgists engaged in industry, chief interest will probably be found in the later chapters, since it is here that they are likely to learn most. These deal with the principles of interchangeable manufacture based upon the Limit System, and systems of assembly and their relation to design and manufacturing sequences are here discussed also. In this connection the advantages of standardisation will be clear, but while these early chapters deal with the fundamentals underlying the design of mechanical products intended to be made on a repetition basis, the final sections of the book deal with the preparation of information necessary for the manufacture and assembly of finished articles. It will thus be seen that this small book provides much information which can normally only be acquired through a prolonged and varied experience of production in industry.

W. F. CHUBB.

IRON AND STEEL INSTITUTE. "*Carnegie Scholarship Memoirs.*" Vol. XXVII. Edited by K. Headlam-Morley. 8vo. pp. ix + 192. Illustrated. London, 1938: The Institute. (Price 16*s.*)

The Carnegie Scholarship Memoirs contain the results of original research work in the metallurgy of iron and steel, carried out by research workers with the aid of grants made by the Iron and Steel Institute from the Andrew Carnegie Research Fund. The present volume contains the following reports: Equilibrium at High Temperatures in

Systems Containing Iron Oxides, by J. White; The Influence of Some Special Additions on Certain Properties of Cast Iron, by P. G. Bastien and L. Guillet, jun.; Breakdown Phenomena in Alitised Coatings on Carbon-Bearing Iron, by W. Baukloh and W. Böke; The Mechanism of the Reaction between Hydrogen and Carbon in Iron. A Contribution on the Mechanism of Heterogeneous Reactions, by W. Baukloh and B. Knapp; The Structure of Cast Steel in Relation to the Rate of Cooling, by J. A. Verö.

"*Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung zu Düsseldorf.*" Herausgegeben von Friedrich Körber. Band XX. La. 8vo. pp. 306. Illustrated. Düsseldorf, 1938: Verlag Stahleisen m.b.H. (Price 33 R.M. 25% reduction for foreign purchasers.)

This volume contains 26 papers recording the results of metallurgical investigations carried out at the Kaiser-Wilhelm-Institut für Eisenforschung under the able directorship of Dr. Friedrich Körber. The papers deal with many aspects of metallurgy and are of special interest to those engaged in the manufacture and testing of ferrous products. Abstracts of the papers are to be found in recent issues of the *Bulletin and Journal of the Iron and Steel Institute.* The present volume contains the following: Fatigue Testing of Steel Wire under Fluctuating Tensile Stress. II.—Influence of the Drawing Conditions on the Fatigue Strength of Steel Wire in Tension under Stresses Fluctuating Between a Minimum and a Maximum Value, by A. Pomp and M. Hempel; Fatigue Testing and Crystal Structure, by H. Möller and M. Hempel; The Application of Potentiometric Volumetric Analysis in the Steelworks Laboratory. VIII.—A Simplified Method for the Co-determination of Manganese, Chromium and Vanadium, by P. Dickens and G. Thanheiser; Experiments on the Cold Rolling of Steel Clad with Nickel, Copper and Brass, by A. Pomp and G. Weddige; The Influence of the Cooling Rate on the Transformations in Steels. II.—On an Electrical Elongation Recorder and the Effect of Slow Cooling Rates on the Transformation Temperatures of Carbon Steels, by F. Wever and A. Rose. III.—On a Photo-Electric Elongation Recorder and the Effect of Very Slow Rates of Cooling on the Transformation of Carbon Steels, by H. Lange; Method of Economising in Manganese in the Open-Hearth Process, by P. Bardenheuer and G. Thanheiser; The Tendency of Chromium-Molybdenum Steels to Form Fissures on Welding, by P. Bardenheuer and W. Bottenberg; Welding Rods for the Acetylene Welding of Steels with Special Reference to the Tendency to Form Fissures, by P. Bardenheuer and W. Bottenberg; On Magnetic Methods of Testing Materials, by F. Wever and H. Hänsel; Comparative Investigations of the Depth-Hardening Properties of Chromium-Molybdenum Heat-Treatable Steels, by A. Pomp and A. Krisch; On the Progress of the Austenite Transformation during the Cooling of Iron-Nickel-Carbon Alloys, by H. Lange and K. Mathieu; The Structure and Mechanical Properties of Heat-Treated Cast Irons, by P. Bardenheuer and W. Bröhl; The Binary Iron-Rhenium System, by H. Eggers; The Effect of the Size of the Specimen and of the Dependency of the Line Intensity on the Excitation on the Mean Errors in Spectrum Analysis, by G. Thanheiser and J. Heyes; The Spread of Metal when Round High-Carbon Steel Wire is Rolled Flat, by A. Pomp and H. Höhle; Determination on the Initial Diameter of Round Wire before Rolling Flat, by W. Lueg and A. Pomp; The Iron-Niobium Diagram, by H. Eggers and W. Peter; The Iron Corner of the Iron-Niobium-Carbon Diagram below 1050° C., by H. Eggers and W. Peter; The Influence of the Rate of Cooling on the Transformation and

Properties of Vanadium Steels, by F. Wever and A. Rose; Fatigue Testing and Crystal Structure. II.—On the Subject of Recrystallisation in Fatigue Failure, by H. Möller and M. Hempel; A Magnetic Balance for Saturation Measurements. The Saturation Points of Cementite and Carbon Steels and their Dependency on Temperature and Preliminary Treatment, by H. Lange and K. Mathieu; The Evaluation of Time-Elongation Curves by Different Methods to Determine the Creep Limit and a Comparison of the Results with those of Long Time Tests, by A. Pomp and A. Krisch; Power Requirements and Flow of Material in Drop Forging, by A. Pomp, T. Münker and W. Lueg; Recent Results from the Magnetising Roasting of Brown Iron Ores, by W. Luyken and G. Kremer; The Effect of the Chemically Combined Water on the Fuel Consumption when Sintering Iron Ores, by W. Luyken and G. Kremer.

REDPATH, BROWN & CO., LTD. "*Structural Steelwork. Tables and Data.*" (1938 Pocket Edition.) Sm. 8vo. pp. v + 103. London, Edinburgh etc.: The Company.

This small publication is based on the main handbook, "Structural Steelwork—1938," issued by the Company, and the tables have been selected to combine the maximum of utility with a size convenient for the pocket. Properties and safe loads are given for joists and joist compounds as beams and as stanchions, filler joist floors, solid round columns, slab bases and grillages. Other tables relate to rivets and bolts, weights of sections and materials, mathematical tables and conversion equivalents. The calculations are in accordance with the requirements of the latest British Standard Specifications.

ROLLASON, E. C. "*Metallurgy for Engineers.*" 8vo. pp. viii + 272. Illustrated. London (1939): Edward Arnold & Co. (Price 10*s.*)

As mentioned in the preface to this book, the need of the engineer for metallurgical training has been recognised in the Universities and Technical Colleges throughout this country, and in consequence courses of instruction are now being provided to satisfy not only the requirements of a degree in engineering, but also to meet the demands of the Institutions of Mechanical, Production and Civil Engineering. With these in mind the author has felt the need for a general text-book on metallurgy which will provide a brief description of both theory and practice in metallurgy, but written with a special appeal to students of engineering. In undertaking such a work the special requirements of the City and Guilds of London Institute have not been overlooked, but it is not claimed for this book that it is sufficient of itself to satisfy all the demands of engineering examinations, and it is accordingly recommended that it be used in conjunction with a teacher who will be able to expand the text as required. Among the requirements of these examinations, however, may be mentioned a general knowledge of the constitution of metals and alloys, and an adequate appreciation of the properties and chief characteristics. Some knowledge of production methods is also now essential, and the student, in entering for such examinations, is also recommended to acquaint himself with modern conceptions of atomic theory, although a detailed knowledge of any related mathematical and physical theories is not required. This knowledge as to the constitution of metals and alloys is moreover essential to a more thorough understanding of the thermal and mechanical treatments to which metals are now subjected as essential stages in fabrication and manufacturing processes. Another impera-

tive need in a work of this type is that the engineering student must be made to realise how the properties of metals and alloys are dependent upon method of manufacture, and it is also essential to show how their properties can be deliberately modified by suitable choice of manufacturing operations and technique. Controversial theory must also be avoided as far as possible, and in particular the treatment accorded to the subject must be essentially practical, otherwise the interest of the engineer in the more metallurgical aspects of his studies is not likely to be aroused. It will, in fact, be clear that unless the subject be presented in an easily read style, interest will not be incited in the first instance, and thus the whole object of the work will be more or less defeated. All these needs and considerations have clearly been uppermost in the author's mind in offering this book as a general treatise on metallurgy for engineers, and it can justifiably be claimed that it satisfies these demands in a very high degree. It does not claim, however, to be complete, as would obviously be impossible in a book of two hundred and ninety-two pages, but it certainly does provide sufficient material to satisfy the demands of engineering examinations when used as recommended. The author's extensive experience in the teaching of metallurgy may, in fact, be regarded as sufficient guarantee in this respect. Turning to a brief synopsis of its contents, the book provides a preliminary discussion on mechanical testing, and then follows an account of the mechanism of solidification in metals. This treatment of the subject leads logically to a fairly detailed treatment of equilibrium diagrams, their construction, interpretation and applications. The fact that despite the great advances in non-ferrous metallurgy the ferrous alloys are still the most important to the engineer is illustrated well in this work, for more than one hundred pages are devoted to the production, properties and uses of ferrous alloys. These include the cast irons, steels and their derivatives obtained by alloying. Heat and mechanical treatments are also discussed. From this it will be clear that the author has condensed all the essential information into a relatively small volume, and it is suggested that in using it the engineering student should concentrate attention on these sections of more fundamental interest, such as those devoted to the constitution of metals and alloys, equilibrium diagrams and their uses. It will then be found that many apparent anomalies in the behaviour of metals during service are easily explainable, and in doing so engineering students are also likely to find that their studies of the properties of materials are rendered very much easier. For this purpose, Mr. Rollason's book can be specially recommended.

W. F. CHUBB.

SOCIETY OF CHEMICAL INDUSTRY. "*Reports of the Progress of Applied Chemistry.*" Vol. XXIII. 1938. 8vo. pp. 856. London: Society of Chemical Industry. (Price 7*s.* 6*d.* to Members of the Society, 12*s.* 6*d.* to others.)

This volume consists of surveys by leading authorities on the progress in 1938 of Applied Chemistry in its numerous branches. The reports contained in the present volume, many of which are of interest to those engaged in the manufacture of iron and steel, are as follows: General, Plant and Machinery, by S. G. M. Ure and F. J. Bailey; Fuel, by J. G. King and C. M. Cawley; Gas, Destructive Distillation, Tar, and Tar Products, by H. Hollings and W. A. Voss; Mineral Oils, by W. W. Goulson; Intermediates and Colouring Matters, by E. H. Rodd; The Chemical Technology of Textile Fibres. The Protein Fibres, by C. S. Whewell and J. B. Speakman; Cellulose Textile Materials, by J. M. Preston, H. A. Turner, and C. L. Wall; Pulp and

Paper, by T. Trevor Potts; Acids, Alkalis, Salts, etc., by A. J. Prince and F. J. Wilkins; Glass, by A. Cousen; Refractories, Ceramics, and Cement, by J. A. Sugden; Iron and Steel, by S. J. Kennett; Non-Ferrous Metals, by A. R. Powell; Electrochemical and Electrometallurgical Industries, by J. W. Cuthbertson; Oils, Fats, and Waxes, by T. P. Hilditch; Plastics, by Members of the Plastics Group; Resins, Drying Oils, Varnishes, and Paints, by Members of the Oil and Colour Chemists' Association; Rubber, by T. L. Garner; Leather and Glue, by D. Burton; Soils and Fertilisers, by G. V. Jacks; Sugars, by H. C. Siegfried de Whalley; The Fermentation Industries, by R. H. Hopkins, F. W. Norris, and I. A. Preece; Foods, by T. Moran; Fine Chemicals, Medicinal Substances, and Essential Oils, by T. M. Sharp and W. Solomon; Photographic Materials and Processes, by C. Waller; Explosives, 1937–1938, by J. Weir; Sanitation, Water Purification, Etc., by J. H. Coste.

VEREIN DEUTSCHER EISENHÜTTENLEUTE. "*Leitfaden für das Rechnungswesen in der Eisen schaffenden Industrie.*" I. Band: "*Kostenrechnung, Bewertung und Erfolgsrechnung.*" Herausgegeben im Auftrage der Wirtschaftsgruppe Eisen schaffenden Industrie vom Ausschuss für Betriebswirtschaft des Vereins deutscher Eisenhüttenleute. Bearbeitet von: K. Kleine, H. Kreis, A. Müller. 8vo. pp. 99. Düsseldorf, 1938: Verlag Stahleisen m.b.H. (Price 4.50 R.M.)

In 1922 the Verein Deutscher Eisenhüttenleute established a Committee to examine, and if possible unify, costing methods in German Iron and Steel Practice. The Proceedings of this Committee were summarised in a publication issued in 1927 by Dr. K. Rummel, entitled "Das Selbstkostenwesen auf Eisenhüttenwerken." Since that date the system has been applied to a number of individual processes of iron and steel production, details of which have been given in a series of papers and reports published in the reports of the Ausschuss für Betriebswirtschaft, "Stahl und Eisen" and "Archiv für das Eisenhüttenwesen." In 1936, arising out of the requirements of the four-year plan, the Minister of Economics issued an order that the costing system devised by the V.D.E. Committee should be effectively applied in general accountancy in the German iron and steel industry, and the publication under review is the result of the work of the Committee appointed to this end. The report is concerned particularly with the co-ordination of works' costing with financial accountancy, and is directed to secure uniformity of costing and accountancy in the iron and steel industry, with a view to ensuring, for purposes of national administration, that methods are established in individual works that can be co-ordinated on a convenient basis for the industry as a whole. In the first section, after brief remarks regarding the aims of works' accountancy and the relationship between cost and financial accountancy, the methods of book-keeping to ensure correlation between works' costs and monthly or other interim profit and loss statements are discussed in some detail, so as to ensure that methods in different works are on a common basis. Such book-keeping records include cost of social services, depreciation, interest and taxes, cost accounts, proceeds accounts, selling a plant or building accounts; each department in the works should carry its own set of accounts, plants for the production of ancillary materials used in manufacture or by-products being treated separately. The second portion of the book deals essentially with the principles of cost accountancy, and is particularly interesting to British iron and steel cost accountants as exemplifying the methods of costing

that have been developed in Germany; the discussion of the difficulties of costing in works making a wide variety of products is of special interest to those who have to deal with similar problems in this country. In Great Britain a system of cost accountancy has been developed, through the Standing Costs Committee of the Iron and Steel Federation, in which the elements of cost are divided into the following groups :—

Productive materials.
Productive labour.
Operating supplies.
Services.
Expenses.

In costing items in these groups the same fundamental units of cost are used; the elements of steam service cost, for example, include productive materials (water and fuel), productive labour, productive services (*e.g.* internal handling and electricity), general services (ash disposal, laboratory, etc.), maintenance services and works control and administrative expenses, an allocation being made to the department or product concerned. Sub-division in the German system is not carried out to the same extent, but it is quite obvious that the difficulties that have been experienced in this country and that led to the development of this very complete but complicated scheme are fully appreciated. It is pointed out, for eaxmple, that whilst the determination of the cost of such services as steam and energy and the allocation to the user departments is comparatively simple, as these services can be directly measured, the determination of cost of maintenance and repair services is more complicated, particularly where the intermediate use of a machine-shop is involved, the cost of which must be determined in order to obtain maintenance or repair cost in any particular instance. In order to ensure uniformity, however, the report deals essentially with the principles of costing in such cases, a detailed discussion being given of such items as the cost of raw materials, fuel and power, wages, supervision, social services, ancillary processes and plant, transport, insurance, office services, depreciation and interest and taxation. Examples are given of costing of various departments, blast-furnaces, steel works and mills. In the third section the principles of valuation are discussed, but it is emphasised that there are no general rules that can be established, the methods of valuation being dependent essentially on the objects aimed at; thus in an integrated works, valuation of the product of one department which may be the raw material of the next should be based on net actual cost, with no interprofit, profit or loss being determined for the works as a whole. In long-term valuation of stocks, on the other hand, and in preparing annual balance sheets, market price has to be taken into consideration, this being particularly important when the market price is less than production cost. The work concludes with a brief note on the methods required to adjust monthly or interim profit and loss statements with the annual balance sheet. The report is of interest as an attempt to correlate on a standard basis the activities of the merchant with those of the engineer and producer. It differs from the work and reports of the British Standing Costs Committee in that it deals essentially with principles rather than detail, the latter being left to individual works. In Great Britain, on the other hand, it has been found preferable, and in fact necessary, to deal with the costing of iron and steel production in the fullest possible detail. Rigid definition has had to be made of the elements and the range of costing for practically every item on the cost sheet. It is fully appreciated in this country that for the smaller works the detailed sub-division of cost into these principal elements would be impossible, and in fact unnecessary, but in such cases a simplified system can be evolved which can be operated with a minimum of clerical labour, and

which still embodies the main principles and elements which are necessary in the case of the large integrated plants making a wide range of products. In the case of the small works in this country the process of modification of the British uniform costing system is one of simplification and of combination of items which have to be costed separately in the larger plants. In the German work under review the opposite method has been adopted, principles are laid down which can be universally adopted, the function of individual producers being to develop and elaborate these principles in order to meet their own individual requirements. The report is logical, well presented and particularly stimulating in the suggestions that are put forward for the correlation of works' costing with financial accountancy.

E. C. EVANS.

MINERAL RESOURCES

The Newcastle Coalfield. J. Fallins. (Broken Hill Proprietary Review, 1939, vol. 16, Feb., pp. 1–5). The author gives an account of the history, development and present mining practice at the Newcastle coalfield in New South Wales.

The New Coal and Iron Economy in Czecho-Slovakia. G. Behaghel. (Stahl und Eisen, 1939, vol. 59, Apr. 13, pp. 445–450). The author presents a survey of the deposits and production of bituminous coal, brown coal, iron ore and manganese ore in Czecho-slovakia with special reference to the position created by this country becoming a German protectorate.

The " El Teuler " Magnetic Iron Ore Bed near Cala (Province of Huelva). H. Quiring. (Zeitschrift für praktische Geologie, 1939, vol. 47, Feb., pp. 33–38; Mar., pp. 53–55). The author gives a geological description of the magnetic iron ore deposits in the northeast of the province of Huelva in Spain.

Rumanian Ores. E. Kohl. (Metallwirtschaft, 1939, vol. 18, Apr. 14, pp. 328–332). The author presents a survey of the occurrence of metalliferous ores in Rumania. The reserves of iron ore are estimated to amount to 33,000,000 tons, and the quantity mined has risen from 13,800 tons in 1933 to 128,600 tons in 1937.

Foundry Iron. J. P. Dovel. (Steel, 1939, vol. 104, Apr. 17, p. 48). The author points to some of the differences between the brown ores from the southern Appalachian fields and the red ores from the Birmingham district of Alabama, the most important of which is that the former contains more manganese. He discusses the effects of these characteristics upon the properties of the iron produced from them.

The Turkish Chrome Ores. (Teknisk Tidskrift, 1939, vol. 69, Apr. 8, Bergsvetenskap, pp. 30–31). Brief particulars are given of the occurrence and production of chrome ores in Turkey. The quantity exported has risen from a negligible amount in 1928 to 150,000 tons in 1936. The analysis of the ore shows that it contains 48–58% of chromic oxide.

ORES—MINING AND TREATMENT

Reconstruction of the Irthlingborough Iron Ore Mines. (Iron and Coal Trades Review, 1939, vol. 138, Apr. 14, pp. 655–656). Following a brief geological description of the 3000-acre iron-ore property in Northamptonshire acquired in 1935 by Richard Thomas and Co., a description is given of the new plant and methods of working put in operation by this company by means of which the output has been brought up to 7000 tons per week.

Roller Crushers. W. T. W. Miller and G. Badger. (Proceedings of the Institution of Mechanical Engineers, 1939, vol. 141, Mar., pp. 69–80). The authors describe the development of roll crushers for the reduction in size of ore, stone, coal or chemical preparations of similar densities. They show that single-roll breakers originally developed for crushing coal are now applied for the reduction of semi-hard slippery materials such as phosphate, gypsum, shale and limestone. Two-roll crushers form the most popular class whilst three-roller mills have not proved very successful. Four-roller machines have proved useful for crushing coal and six-roller machines are not very common. The authors examine the factors which influence the performance of the rolls, develop a formula for calculating their capacity and present a time-factor diagram which shows why rolls of large diameter can be run with advantage at the higher circumferential speeds.

Theoretical Study of the Crushing of Hard Materials : the Limit of the Reduction Proportion. E. C. Blanc. (Revue de l'Industrie Minérale, Mémoires, 1939, Apr. 1, pp. 106–113). The author discusses the general theory and practice of crushing hard materials and presents formulæ for calculating the limit of reduction possible in the case of isolated pieces and of quantities of mixed sizes.

Investigation of the Working of the Polizius Agglomeration Furnace at the Frunze Plant. V. I. Bezhanishvili and L. N. Shvetsov. (Metallurg, 1938, No. 7–8, pp. 91–102). (In Russian). Experimental work on the production of agglomerate from the residues of burnt pyrites, with and without additions (up to 26%) of blast-furnace flue dust, intended for use as a substitute for ore in blast-furnaces, is reported. An inclined rotary furnace 60·4 m. long was used with either coal dust or coke-oven gas as fuel. The work was concerned mainly with the determination of the fuel consumption, the operating temperatures of the furnace and the characteristics of the agglomerate. The favourable effect of preliminary mixing of the charge on the uniformity of the agglomerate was noted.

The Technology and Probable Future Development of the Process of Agglomerating Ores in Suspension. A. Parfenov. (Stal, 1938,

No. 8–9, pp. 8–13). (In Russian). The process of agglomerating ores consists of allowing the finely powdered material to fall through an ascending current of hot gas which causes the material to sinter. Experimental results obtained on a pilot plant, a description of which is given, are discussed. The author is of the opinion that the greater part of the agglomeration process takes place in the discharging mechanism. The growth of the finer fractions, which takes place as a result of their melting during the descent through the furnace, is regarded only as a preparatory process. The properties of the agglomerate may be controlled within very wide limits, and it is possible to work the plant so that none of the product requires resintering. The plant used was of the batch type as far as the discharge end was concerned. A continuous discharge mechanism with a granulator is now being developed. The oil-fired furnace had an output capacity of 0·776 kg. per hr. per cu. m. of gas. This process of agglomeration appears to be particularly applicable to the sintering of flue dust, the sintering of ore for small blast-furnaces, the treatment of ores which are difficult to sinter and possibly also to the production of sponge-iron, to the dead-burning of dolomite fines and the production of cement clinker.

On the Fixation of Lime when Sintering Iron Ore. J. Klärding. (Archiv für das Eisenhüttenwesen, 1939, vol. 12, May, pp. 525–528). The author refers to his own previous investigation of the sintering of German Fortuna ore with quick lime at 1000–1300° C. and the reduction of the sinter, which showed that the alternating effects of lime and silica on the reduction when expressed graphically (by plotting the weight-per cent. of oxygen in the sinter against the percentage of carbon dioxide in the gas after the test) produced curves similar to that for pure iron oxide. He also describes his study of the effects of the sintering time and temperature upon the proportion of free lime using the same kind of ore, as well as the effect of the lime upon the viscosity of the blast-furnace slag. He found that additions of lime before sintering led to a better yield from the magnetic separator as this addition liberated the iron oxide fixed by the silica.

REFRACTORY MATERIALS

(Continued from pp. 1 A–3 A)

The De-Aëration of Plastic Ceramic Masses. F. Gareis. (Archiv für das Eisenhüttenwesen, 1939, vol. 12, Apr., pp. 511–516). The author describes a new vacuum-extrusion press for removing air from clays used for making refractory and acid-resisting bricks. The advantage claimed for this apparatus is that the exhauster can be connected at any point in the sequence of the clay-preparation processes. The author discusses the effect of de-aëration with subsequent compression upon the properties of the bricks produced.

Refractories of the Alumina-Silica Series. F. A. Harvey. (Electrochemical Society, Apr., 1939, Preprint 25). The author discusses the silica-alumina diagram and the effects of increasing proportions of alumina in silica-alumina refractory bricks. He also considers the effects of oxides of titanium, iron, calcium, magnesium, sodium and potassium and concludes by reviewing some of the recognised American methods of testing refractories.

Influence of Fluidity, Hydrodynamic Characteristics and Solvent Action of Slag on the Destruction of Refractories at High Temperature. K. Endell, R. Fehling and R. Kley. (Journal of the American Ceramic Society, 1939, vol. 22, Apr., pp. 105–116). As a result of the investigations described the authors find that the degree of attack by a bath of molten material on a fireclay refractory is almost independent of the chemical composition of the bath, but it increases markedly with increasing fluidity of the slag or glass. The authors studied the velocity of flow and film thickness of oils, slags and glasses and their relation to the angle of inclination, width of path of flow and viscosity. They describe a graphical method of determining the solubility of a refractory in a given slag. In conclusion they state that appreciable resistance to slag attack can be achieved only by selecting a refractory of low solubility in the corroding slag and by reducing the surface temperature of the refractory to less than 50° C. above the melting point of the slag in order to build up a stable plastic protective film next to the wall.

Reactions of Slag with Refractories : I. Surface Reactions. H. G. Schurecht. (Journal of the American Ceramic Society, 1939, vol. 22, Apr., pp. 116–123). The author describes several new methods of studying the surface reactions of slags, glass and Portland cement clinker with refractories. These methods of testing showed that the slag reactions occurring in basic and acid open-hearth furnaces are governed largely by the relative acidity

or basicity of the slags and refractories; thus, a basic slag naturally produces a greater reaction on an acid refractory than on a basic one.

The Relation of Low Weight to the Physical Properties of Furnace Refractories. C. L. Norton, jun. (Electrochemical Society, Apr., 1939. Preprint 26). The author discusses the weight and porosity of insulating firebricks in relation to their thermal conductivity, heat-absorption capacity, spalling, cold crushing strength, refractoriness-under-load and resistance to slag erosion and abrasion. He finds that the weight of a refractory is a direct indication of its thermal conductivity and that low weight is not directly related to shrinkage, or life, or the ability to carry a load at high temperatures.

Methods of Calculating the Dimensions of Refractory Brick Structures. D. Petit. (Chaleur et Industrie, 1939, vol. 20, Feb., pp. 239–248; Mar., pp. 273–288). After discussing various methods of determining the heat-resisting properties of refractory bricks and the application of test results as a means of determining (1) the maximum temperature at which an existing plant may be operated, and (2) the factors limiting the design of a new plant which is to be operated at a given temperature, the author develops a method of calculating safe working loads and safe temperatures. This method is based on the use of graphs in which curves show the percentage depression induced by different loads at different temperatures in the refractory material under consideration. In the concluding part of his paper he reproduces these graphs for twelve different kinds of refractory brick.

Carbon Linings for Blast-Furnaces. F. Singer. (Metals and Alloys, 1939, vol. 10, Apr., pp. 105–108). The author describes first the manufacture of carbon bricks. These are made from a mixture of a good foundry coke crushed to about 1-mm. grains and a solution of pitch in the highest boiling-point constituents of coal tar, the proportion being one part by weight of tar to four or five parts of coke. The mixture is rammed into moulds by hand or by pneumatic rammers; small bricks may be moulded with a hydraulic press. The bricks are burned in batches in single-chamber, down-draught kilns, all spaces between individual bricks and between the bricks and the kiln walls being filled up with crushed coke. They are burned at a temperature of about 1000° C. These bricks are now being used in Germany under the hearths of blast-furnaces and although they cost more than twice as much per ton as fireclay bricks there are technical advantages which justify their use. Their softening point is above Seger Cone 42, the thermal conductivity is fifteen to twenty times that of fireclay bricks and the coefficient of expansion of the material within the range 0–900° C. is about $5{\cdot}8 \times 10^{-6}$, the expansion curve being practically a straight line. When blowing-in a blast-furnace a layer of firebrick slabs is put in over the carbon brick lining of the

hearth, and although the former is soon destroyed by the iron and slag it lasts long enough to protect the lining while the danger of oxidation exists. Carbon bricks cannot be put in near the tap hole. Blast-furnaces lined with carbon bricks in Germany have been found to run for five or six years and to have produced 1,000,000 tons of pig iron without relining the hearth. Carbon bricks or blocks can be produced in large sizes without difficulty, thus reducing the number of joints; blocks measuring $17\frac{3}{4} \times 12\frac{3}{4} \times 6\frac{3}{8}$ in. are now common in Germany. In conclusion the author points out that a fair comparison between the efficiencies of carbon brick linings in Germany and best quality firebrick linings in Americe cannot yet be made because of the number of factors, such as nature of the charge, design of the furnace and the number and duration of stoppages, which must be taken into account.

Chrome-Magnesite Bricks for Open-Hearth Furnaces. J. H. Chesters and T. R. Lynam. (Journal of the American Ceramic Society, 1939, vol. 22, Apr., pp. 97–104). The authors discuss the advantages and limitations of chrome-magnesite bricks as substitutes for silica bricks in open-hearth furnaces. They consider the properties of a number of British and Continental chrome-magnesite bricks. They state that after about six to ten weeks use chrome-magnesite bricks absorb sufficient iron oxide to cause considerable spalling; the brickwork begins to spall badly exposing new surfaces which in turn absorb iron oxide, expand and spall. Laboratory experiments show that it is possible to make chrome-magnesite bricks possessing the desired degree of resistance to thermal shock and at the same time having a much lower coefficient of expansion than those normally employed.

Bringing Insulation Facts up to Date. G. E. Grimshaw. (Industrial Heating, 1939, vol. 6, Jan., pp. 61–64; Feb., pp. 157–161; Mar., pp. 253–260; Apr., pp. 343–346). In Part I. of this series the author considers the application of heat-insulating materials to industrial furnaces working at temperatures from 400° to 2000° F. heated by manufactured or natural gas. In Part II. he explains the graphical method of E. Schmidt for determining the theoretical heating time and the temperature distribution in a furnace wall. In Part III. he deals with the insulation of industrial ovens working at 200–1000° F. and describes the wall structures enclosing the ovens and the thermal and physical properties of the insulating materials used in their construction.

FUEL

(Continued from pp. 4 A–5 A)

The Problem of Sulphur in Coal. G. W. Himus and A. C. Egerton. (Coal Combustion Appliance Makers' Association, Mar., 1939 : Iron and Coal Trades Review, 1939, vol. 138, Apr. 14, pp. 663–664). After discussing the amount of sulphur present in coal as mined the authors consider what proportion of this can be removed during the cleaning and preparation of the coal. From this they proceed to a consideration of the behaviour of the sulphur during coal combustion and carbonisation with special reference to coke-oven practice.

The Variability of New South Wales Coals with Respect to Ash Content. G. B. Howarth. (New South Wales Department of Mines, 1939, Fuel Research Paper No. 1). The author describes his investigation of the ash content of New South Wales coals. He found that those tested have a close similarity to the United Kingdom coals used in establishing the British Standard Specifications for coal sampling, and these specifications may therefore be applied with confidence to New South Wales coals.

The Occurrence of Titanium and Nickel in the Ash from some Special Coals. J. H. Jones and J. M. Miller. (Chemistry and Industry, 1939, vol. 17, Mar. 18, pp. 237–245). The authors describe the formations known as " cauldrons " which have been found in the shales overlying some of the coal seams of Northumberland and Durham. These are large conical masses of shale 7 or 8 ft. high. In many cases some brilliantly glossy coal of the vitrain type is present on the surface of the cauldron, and it has been found that the ash from this coal contains abnormally large percentages of titanium oxide and nickel oxide. The authors compare the analyses of this coal and ash with the analyses of those in the Kent coalfield and discuss the possible causes of the presence of these oxides.

Cleaning of Coal by Heavy Liquids. M. G. Driessen. (Colliery Guardian, 1939, vol. 158, May 5, pp. 783–788 ; May 12, pp. 832–833). After giving some information on the occurrence and properties of loess (an earth widely distributed over the globe concerning the origin of which many theories exist), the author discusses the loess obtained in the south of Holland and the preparation of a loess suspension (sp. gr. 1·45) for washing coal. He then describes in detail the Staatsmijnen-Loess Washing System which has been developed by the Dutch State Mines. This paper also appeared in Iron and Coal Trades Review, 1939, vol. 138, May 12, pp. 831–832 and Génie Civil, 1939, vol. 114, June 10, pp. 484–487.

Barvoys Washery at Wingate. (Colliery Engineering, 1939, vol. 5, May, pp. 169–175). A detailed and illustrated description is presented of the coal-washing plant of The Wingate Coal Co., Ltd. This plant operates on the Barvoys system which was invented by G. Jan de Vooys (*see* Journ. I. and S.I., 1935, No. I., p. 337). It has now been running sufficiently long for a reliable estimate to be formed of its capabilities. Various tests have shown that the difference between the actual ash content and the fixed ash corresponding to the yield obtained is about 0·05% for coal above 2½ in., about 0·08% for 2½ – ⅞ in. coal and about 0·1% for ⅞ – ¼ in. coal. It is estimated that the yield is at least 3% greater for the same ash content than that which would be obtained from a normal type of washer, corresponding to an increase in yield, at full capacity, of about 4 tons per hr. A shorter description of this plant is given in Engineering, 1939, vol. 147, June 2, pp. 639–641.

Coke Ovens for Tinplate Manufacture. (Coal Carbonisation, 1939, vol. 5, May, pp. 72–80). An illustrated description is given of the coke-oven and by-product plant at the Ebbw Vale Works of Richard Thomas and Co., Ltd. This plant includes a battery of sixty-five Becker ovens, each oven being 40 ft. 8 in. long and 12 ft. 6 in. high with a mean width of 16 in., and the battery is capable of producing 6300 tons of blast-furnace coke per week.

The Organisation of a Large Modern Coke-Oven Plant. The Preparation of Small Coke with a View to Complete Utilisation of the Gases. C. Berthelot. (Revue de Métallurgie, Mémoires, 1939, vol. 36, Feb., pp. 65–78; Mar., pp. 112–127). In considering the organisation of a modern coke-oven plant the author explains the principles of flow- and pressure-regulating instruments; from this he proceeds to discuss the methods of adjusting coke-oven gas production to consumption and as examples of these methods he describes the lay-out of some modern coke-oven and by-product plants in Germany, Belgium, Holland, Italy and France.

Electric Carbonization of Coal. H. Stevens. (Electrochemical Society, Apr., 1939, Preprint 19). The author describes the 30-ton electric carbonising retort at the Delray Plant of The Detroit Edison Co. This is a vertical retort 6 ft. inside dia. × 40 ft. high. A starting fuse consisting of a conductor-pipe filled with coke passes down the centre and is connected to the top and bottom electrodes. When the current is switched on the starting fuse heats the coal surrounding it driving the moisture, gases and oil outwards. As the coal near the fuse carbonises first and becomes more dense than the loose coke forming the fuse the former becomes a better conductor and carries more of the current. The zone in which the heat is generated thus travels outward and the carbonisation process is completed first near the centre and last at the circumference. A very high thermal efficiency is claimed for this process. The current is supplied from a single-phase, 60-cycle, 850 kVA. transformer;

the power factor averages 0·85, and it requires 350 kWh. to carbonise a ton of moist coal under sporadic operating conditions. The author compares the operating costs, and the properties of the coke, gas and oil produced by the electric retort with those of the products of ordinary coke-ovens.

The Action of Solvents on Coal Tars. J. Aubert and I. Klauzner. (Revue de l'Industrie Minérale, Mémoires, 1939, Apr. 15, pp. 119–139). The author describes methods of separating the soluble from the insoluble portions of crude tar by filtration and the use of different solvents.

Foundry Coke : An Interpretive Discussion. B. P. Mulcahy. (Fuel in Science and Practice, 1939, vol. 18, Apr., pp. 100–109). After comparing the functions of blast-furnace, foundry and domestic cokes the author discusses some of the methods of testing coke specified by the American Society for Testing Materials. He points out that the methods of testing foundry coke are too limited to evaluate properly the difference between cokes and for this reason producers of foundry coke are developing more exacting tests on their own initiative. He concludes by describing the investigations now in progress of the factors affecting the combustion of foundry coke and their correlation.

Thylox Process for the Recovery of Sulphur from Gases Containing Hydrogen Sulphide. G. E. Foxwell and A. Grounds. (Journal of the Institute of Fuel, 1939, vol. 12, Apr., pp. 231–238). The authors describe the Thylox process of sulphur recovery and give the operating results of two recent installations in Japan.

The Evolution of the Technique of Hydrogenating Coal and Heavy Oils. C. Berthelot. (Génie Civil, 1939, vol. 114, Mar. 11, pp. 214–216; Mar. 18, pp. 234–237). In the first part of this article the author points out the two directions in which the production of petrol by hydrogenation is progressing. The first is the production of oil from crude tar and creosote from coal, lignite, petroleum residues, and from oils from bituminous schist; and the second is the production of aviation petrol with an octane number of 84 or higher. He then gives some particulars of the situation and capacity of hydrogenation plants now producing and those under construction and concludes this part by discussing the economic structure of the industry. In the second part of his paper the author discusses the chemistry of the production of aviation petrol by the hydrogenation process.

Hydrogenation of Spores, Resins and other Attrital Constituents of Coal. C. H. Fisher, G. C. Sprunk, A. Eisner, L. Clarke and H. H. Storch. (Fuel in Science and Practice, 1939, vol. 18, May, pp. 132–141). The authors present the results obtained by a study of the destructive hydrogenation of the constituents occurring in the attritus or dull portion of coal.

PRODUCTION OF IRON

(Continued from pp. 6 A–8 A)

New Republic Blast-Furnace Goes into Operation. J. J. Carpenter. (Blast Furnace and Steel Plant, 1939, vol. 27, Feb., pp. 167–171). The author describes with diagrams and illustrations the new No. 3 blast-furnace of the Republic Steel Corporation and gives particulars of the skip hoist, the bell mechanism, the method of controlling the charge and the hot-blast equipment. (*See* Journ. I. and S.I., 1939, No. I., p. 265 A).

Stoppages of Blast-Furnaces at the Kirov Works. N. Krasavtsev. (Stal, 1938, No. 8–9, pp. 1–8). (In Russian). Stoppages at the Kirov blast-furnaces, their causes and methods of dealing with them are considered. The average duration of a stoppage of the blast-furnaces at the works was reduced from 2·86% of the total time in blast in 1933 to 1·84% in 1937. An analysis of the causes shows that replacement of cooling equipment and regular periodical repairs are the most important factors, the next in importance being: troubles with tap-holes during removal of iron and slag, troubles with accessory equipment, abnormal working of the furnaces and causes outside the control of the works. In conclusion some features of the furnaces which are unsatisfactory and which ought to be replaced or modified are mentioned.

The Smelting of Low-Grade Ores, in particular of Roasted Gutmadingen Dogger Ore. A. Wilhelmi. (Stahl und Eisen, 1939, vol. 59, Apr. 27, pp. 501–508). An abridged version of a paper which appeared in Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns, 1938, vol. 6, Nov., pp. 233–249. (*See* Journ. I. and S.I., 1939, No. I., p. 142 A).

Smelting Trials with Salzgitter Ores. H. Schumacher. (Stahl und Eisen, 1939, vol. 59, Mar. 23, pp. 353–361). The author describes a series of tests of the smelting of Salzgitter ores without any additions of richer ores. These tests showed that special sintering of the ore is necessary, quick lime must be added and an acid process used. It was found more economical to prepare the lime in a kiln than on a sinter belt. A good quality road-making material could be made from the acid slag. The author presents numerous tables of consumption, production and cost data, and his general conclusion is that the low-grade, acid, Salzgitter ores can be successfully smelted in Germany.

FOUNDRY PRACTICE

(Continued from pp. 9 A–12 A)

The Work of the Technical Committee of the Institute of British Foundrymen. J. W. Gardom. (Institute of British Foundrymen (International Foundry Congress), London, June, 1939, Preprint No. 687). This report is divided into two sections which deal with (*a*) the formation and working methods of the Technical Committee of the Institute of British Foundrymen, and (*b*) the technical reports which have been published by the Institute during the last nine years, and the programmes of work which the Technical Committee has completed and is carrying on at the present time.

Thirty Years of Progress in Cast Iron. A. B. Everest. (Foundry Trade Journal, 1939, vol. 60, May 4, pp. 366–367). The author reviews the developments in the methods of producing iron castings with improved properties which have taken place during the last thirty years.

The Problem of Economic Foundry Production. E. Ronceray. (Institution of Mechanical Engineers, Apr., 1939 : Foundry Trade Journal, 1939, vol. 60, Apr. 27, pp. 350–354, 358 : Engineering, 1939, vol. 147, Apr. 28, pp. 511–513 : Engineer, 1939, vol. 167, Apr. 28, pp. 542–544 ; May 5, pp. 571–574). The author surveys the present position of mechanised foundry plants and shows that economic methods of manufacture are not limited to foundries on mass production but can be applied to quite modest establishments. He deals with methods of pouring and sampling, the preparation, stocking, transporting and handling of the sand, and conveyors for moulds, and in conclusion he stresses the fact that foundry transport problems have nothing in common with ordinary conveyor problems.

Relationship between the Quality of Iron and Steel Castings and the Nature of the Materials of the Melt. P. Bardenheuer. (Institute of British Foundrymen (International Foundry Congress), London, June, 1939, Preprint No. 674). The author discusses the difficulties encountered in the production of high-quality iron and steel castings with particular reference to those caused by gases in the molten metal, either dissolved in it or formed by the interaction of oxides with carbon. These gases are already present in the materials composing the melt, or are partly absorbed during remelting. Hydrogen is the most important of the gases present in solution. The author points out the injurious effects of hydrogen. He considers next the relationship between the conditions of working in the blast-furnace process and the difficulties encountered with the pig iron obtained owing to an excessive proportion of gases or oxides.

He deals next with the metallurgical reactions which occur in steel melting in so far as they relate to the behaviour of oxygen and the gases, and he concludes by showing how the quality of the castings may suffer by adding alloying materials of high gas content just before pouring.

The Gas-Heated Cupola. K. Emmel. (Giesserei, 1939, vol. 26, Apr. 21, pp. 193–195). The author describes the design of a coke-oven-gas-fired cupola 600 mm. inside dia. with a fore-hearth which he constructed and the results of some melts of white and grey iron obtained with it. The cupola is still only in the development stage. A 4-ton charge consisting of 15% hematite iron, 15% ingot-mould scrap, 25% No. 3 foundry iron and 45% foundry scrap with an average analysis of: carbon 3·40%, manganese 0·60%, silicon 2·60%, phosphorus 0·47% and sulphur 0·080% was melted and cast in pigs. The average analysis of the iron produced was: carbon 3·34%, manganese 0·46%, silicon 2·46%, phosphorus 0·45% and sulphur 0·061%, from which it is seen that the quantities of manganese and sulphur had been reduced by about 23% and 24% respectively. The most economical consumption of gas obtained was 20 cu. m. per 100 kg. of iron.

New Cupola for Producing Controlled Carbon Content. M. Olivo. (Foundry Trade Journal, 1939, vol. 60, Apr. 13, pp. 311–313). After describing and illustrating by diagrams the effects of increasing the blast pressure on the relation between the oxidising and reducing zones in the cupola, the author discusses attempts which have been made to utilise the heat from the dead zone, *i.e.*, from the hearth to the tuyeres, for preheating the blast. He criticises some of these attempts on the ground of complicated apparatus and difficulty of operation, and puts forward his own solution of this problem. The device he has adopted is to arrange a number of annular compartments round the melting zone. These compartments contain heating elements which absorb heat from below the melting zone and transfer it to the blast which is on its way to the tuyeres. The provision of these compartments enables the blast temperature to be varied from 50° to 300° C. and enables the blast to be supplied to different zones of the cupola at different temperatures and pressures and thus provides a hitherto unattained measure of control of the cupola operations. This method of operation has been successfully used in Italy for two years.

Charging the Cupola Mechanically. A. W. Gregg. (Foundry, 1939, vol. 67, Apr., pp. 22–24, 73). The author discusses the data and principles involved in the design of mechanical conveyor equipment for charging one or more cupolas.

Optimum Blast Volume for Cupola Practice. N. Czyzewski. (Institute of British Foundrymen. (International Foundry Congress), London, June, 1939, Preprint No. 672). The optimum blast volume depends on the piping, the conditions of operation of the cupola, and more particularly on the quality of the coke; it

increases with an increase in the consumption of coke and a reduction in its combustibility. With a good foundry coke and using a coke ratio of 9 to 11%, the optimum blast, according to G. Busek, should be about 100 cu. m. per sq. m. per min.

Determining the Operating Conditions of a Cupola. H. Jungbluth and F. Stäblein. (Technische Mitteilungen Krupp, Technische Berichte, 1939, vol. 7, Apr., pp. 41–43). In this mathematical discussion the authors consider the factors determining and the methods of calculating the most economical coke consumption for a cupola.

Foundry Melting Furnaces. S. E. Dawson. (Foundry Trade Journal, 1939, vol. 60, May 4, p. 361). After making a comparison of the approximate costs of melting iron in cupolas, crucibles, coal- and oil-fired rotary furnaces and electric furnaces, the author considers the effect of the amount and condition of the graphitic carbon in the iron upon its properties. He discusses the theory of the refinement of the graphite by bubbling carbon dioxide through the molten metal in the presence of titanium and the improvement in the tensile strength which is obtained by this treatment.

The "Fofumi" Rotary Melting Furnace. (Metallurgia, 1939, vol. 20, May, p. 37). A brief description is given of the Fofumi oil-fired rotary melting furnace manufactured in Sheffield under the Deblanchal patent. It is claimed to have a very low operating cost and also to possess the advantages of low oxidation due to controlled atmosphere, the ability to make alloy additions to the melt without stopping rotation, and to remove samples without stopping the furnace. A recuperator with alloy steel tubes is in the waste-gas flue and this heats the air passing to the burners. The furnace is made in capacities of 1 to 10 tons and it is claimed that a steel charge of 5 tons can be poured in 2 hr. after lighting up. A temperature of 1750° C. can be obtained within 1½ hr. if rapid heating is wanted.

The Compounding of Alloys. (Institute of British Foundrymen (International Foundry Congress), London, June, 1939, Preprint No. 693). In this report by the Association Technique de Fonderie de Belgique, certain general aspects of the compounding of alloys which the foundryman is constrained to consider are discussed. An attempt is made to elucidate a theory of melting and to draw up general rules which are applicable to a specific case, according to prevailing conditions and the features of the particular problem under consideration.

High-Duty Foundry Irons in Great Britain. J. G. Pearce. (Giesserei, 1939, vol. 26, Apr., pp. 196–200). The author considers some of the recent developments of English foundry practice which have led to the manufacture of high-duty cast iron for such applications as crankshafts, camshafts and brake-drums.

Notes on the Design and Operation of the Open-Hearth Furnace

for Melting Malleable Cast Iron. G. R. Shotton. (Institute of British Foundrymen (International Foundry Congress), London, June, 1939, Preprint No. 673). In this paper the author deals with the design of an open-hearth furnace suitable for melting white iron in a malleable iron foundry. In addition to the more important features of design the maintenance of the furnace is detailed, and the working life of the port-blocks, furnace body, and regenerators is recorded, together with the cost of refractories used for maintenance and repairs over a period. The gas-producer plant is also described and details given of the control methods adopted. The operation of the furnace is fully described for both the pre-heating and melting periods. The working of typical charges of 8 tons and 10 tons respectively is detailed, together with particulars of melting losses, and a typical daily time-table covering two heats of 10 tons each is set out. Fuel costs are given in detail, including the fuel consumptions at all stages of pre-heating and melting, on the basis of both 8-ton and 10-ton charges. The total fuel consumption (including the boiler supplying steam to the gas-producer) is given as $7\frac{3}{4}$ cwt. of coal per ton of metal melted when operating on 8-ton charges, while on 10-ton charges this figure is reduced to $6\frac{1}{2}$ cwt. of coal per ton of metal melted. The total melting cost, including fuel and refractories is set out, and shows figures of 9s. and 10s. 6d. per ton of metal melted (exclusive of labour) for 10-ton and 8-ton heats respectively.

Modern Equipment for Clean Annealing Malleable Iron. W. F. Ross. (Heat Treating and Forging, 1939, vol. 25, Apr., pp. 195–199). **Short Cycle Annealing of Malleable Iron.** W. F. Ross. (Iron Age, 1939, vol. 143, May 4, pp. 50–52). After referring to some of the factors affecting the design of continuous malleablising furnaces, the author describes a 340 kW. continuous pusher furnace with a roller hearth, the throughput of which is about 830 lb. per hr. In this unit the charge is loaded on trays, two of which are placed side-by-side in the charging chamber; after closing the outer gas-tight door, two trays of finished material are withdrawn from the discharge end. The inner door of the charging chamber is then opened and hydraulic rams push the two trays into the furnace proper where they become part of the two lines extending through the furnace. The furnace contains five separate and automatically controlled heating and cooling zones and the complete cycle takes about 36 hr.

Organisation and Development of Steel Foundry Research. W. J. Dawson. (Institute of British Foundrymen (International Foundry Congress), London, June, 1939, Preprint No. 681). A brief outline is given of the development of research activities relating to steel founding. The importance of educational facilities for the training of foundry personnel is stressed. Earlier, there had been in general little provision for the purpose, but in later

years considerable impetus to the improvement of education has been given. Special centres of foundry training and research have been established in most of the principal industrial countries, and brief indications are given concerning these institutions in Belgium, France, Germany, Poland, the United States and Great Britain. The nature of the organisations devoted to foundry research in these countries is outlined. The work in Great Britain of the Steel Castings Research Committee and of its two Sub-Committees on Moulding Materials and Foundry Practice respectively, is described in some detail. A summary of the three reports published is given, reference being made to researches on fluidity of steel, the properties of steel which affect the quality of steel castings, the mechanical properties of steel when cooling in the mould, the radiological examination of castings and preliminary work carried out in connection with the testing and improvement of moulding materials. In conclusion, the nature of the problem is discussed in relation to the various factors concerned, and the lines on which further work might be pursued are indicated.

The Renaissance of the Steel Casting and the Rôle of the Metallurgist. F. A. Melmoth. (Institute of British Foundrymen (International Foundry Congress), London, June, 1939, Preprint No. 684). The author points out that while competitive materials have in some spheres reduced the use of steel castings, the application of new metallurgical processes and improvements in quality have created new applications in other spheres. He discusses steelmaking methods in the United States with special reference to the use of deoxidisers, the control of inclusions, the use of complex heat treatments, the improvement of moulding materials and moulding technique. He indicates some directions in which research might be pursued with advantage and concludes with a plea for unorthodoxy of thought in casting design. The paper includes five tables of bibliographies relating to different aspects of the subject of steel castings in which the references are from American technical publications.

Sand Control for Better Castings. H. W. Dietert. (Metals and Alloys, 1939, vol. 10, Mar., pp. 91–95). The author discusses how the moisture content, grain size and clay content of moulding sands affect the quality of a casting, and describes some of the methods now available for determining and controlling these properties.

Notes on Dry-Sand Practice for Steel Castings. C. J. Dadswell and T. R. Walker. (Institute of British Foundrymen (International Foundry Congress), London, June, 1939, Preprint No. 683). The authors briefly describe the materials for dried moulds and compare the practice in different countries. The behaviour of a dried foundry sand is influenced by its strength at high temperatures and also by its strength after subsequent cooling. Moulds should

be dried completely and any comparatively cold areas in the stoves avoided. Dried moulds readily pick up water on standing, so that the face becomes weaker. Paints are often applied to the surfaces of dried sand and composition moulds, both nature and method of application of the paint being important. "Sheffield Compo" has been used in Great Britain for heavy steel castings over a long period, but it is now meeting increased competition from dry sand. Both materials, however, merit further technical investigation, which is now being undertaken.

Bonding Clays and the Properties of Synthetic Moulding Sands. G. H. Piper. (Institute of British Foundrymen (International Foundry Congress), London, June, 1939, Preprint No. 658). The author investigated a number of naturally occurring and proprietary clays to determine their suitability as bonding clays for synthetic moulding sands. He also examined synthetic sands containing about 5% of the clay at various moisture contents. A Wyoming bentonite had the greatest bonding power and synthetic sands containing 3% of bentonite, 5% of Dorset ball clay or 5% of a proprietary clay gave approximately the same maximum green strength. He also investigated the properties of the clays and their relation to bonding power, and a relation was found between bonding power and the quantity of water absorbed by the clays. The results showed that bentonite, the proprietary clay and the more plastic fireclays are most suitable as bonding clays.

Gating and Feeding. A. M. Campbell. (Iron Age, 1939, vol. 143, Mar. 23, pp. 34–38; Apr. 13, pp. 38–41). The author discusses the principles which should be applied to the gating and feeding of castings. This article appeared in Foundry Trade Journal, 1938, vol. 59, Nov. 17, pp. 367–368 and Nov. 24, pp. 383–384. (*See* Journ. I. and S.I., 1939, No. I., p. 85 A).

Gating with Special Reference to the Optimum Flow Conditions in the Molten Metal. E. M. H. Lips. (Institute of British Foundrymen (International Foundry Congress), London, June, 1939, Preprint No. 661). The gating system of a casting should be such that the molten metal flows into the mould in the best possible manner. On the basis of hydrodynamic principles, this condition will be fulfilled when the gating system: (*a*) promotes laminar or streamline flow as much as possible, (*b*) does not cause sudden changes in direction, (*c*) is free from sudden changes in cross-section. It follows from (*a*) that a downgate cannot function as a gate and a riser at the same time. The design of the gating system of a mould based on hydrodynamic principles is illustrated by reference to some examples.

Pattern Development and Molding Methods. E. T. Hynan. (Transactions of the American Foundrymen's Association, 1938, vol. 46, pp. 811–830). The author gives an account of the developments in pattern making and moulding methods at the

Saginaw Malleable Iron Division of the General Motors Corporation during the last twenty years.

Core-Shop Control. J. J. Sheehan. (Institute of British Foundrymen (International Foundry Congress), London, June, 1939, Preprint No. 659). The author describes the theory and practice of core making as employed in an automobile works with departments for steel, grey iron and non-ferrous castings. At this foundry no clay-bonded sands are used in the core shop and the whole of the technique has been built up around the three sands: large grain, medium grain and fine grain. By balancing the proportions of each of the three sands, some measure of control over the following variables is possible: (*a*) permeability of the cores; (*b*) amount of binder used; (*c*) finish on the castings; (*d*) tendency to give expansion cracks; and (*e*) to some extent, sagging of the green cores. Any one variable can be controlled at will, but only at the expense of the others. The author shows that the selection of core binders is based on the requirements in green strength of the core-sand mixtures and the requirements in dry strength of the finished core. The shop conditions described necessitate a careful control of the green strength and the author explains how this is achieved by using a solution of ammonium nitrate in place of the water normally added to the sand mix. Solutions of three strengths are used, the choice from these being governed by the temperature and humidity of the atmosphere. In conclusion the author considers the use of core washes containing silica flour.

Manufacture of Very Light Engineering Castings. A. Burgess. (Foundry Trade Journal, 1939, vol. 60, Apr. 13, pp. 306–309). The author describes some difficulties experienced in moulding and casting in the manufacture of small internal combustion engine castings and parts for model engines, and how these were overcome.

Some Iron Castings for Steelworks Plant. J. Roxburgh. (Institute of British Foundrymen (International Foundry Congress), London, June, 1939, Preprint No. 662). After considering briefly the combination of knowledge and experience which a foundry executive should have, the author describes the technique employed in the moulding and pouring of heavy castings for steelworks plant. The examples he has selected include: a 35-ton casting for a bending press, a reduction drive frame and pinion housings for rolling-mill plant, a 20-ton slag ladle and a steam-hammer cylinder.

Defects in Electrically-Melted Chilled Rolls. F. Bondi. (Institute of British Foundrymen (International Foundry Congress), London, June, 1939, Preprint No. 694). After alluding briefly to the advantages and disadvantages of the electric furnace for the manufacture of chilled rolls, the author describes the characteristics of this method of melting. He considers next the defects encountered in the course of several years of production with

special reference to the casting of rolls up to 1400 mm. long by 560 mm. in dia. He deals with these in five classes, namely: (1) explosions during pouring; (2) cracking; (3) cavities and irregular surface of the body of the roll; (4) brittle necks; and (5) eccentricity and variation in hardness. In conclusion he indicates the possible remedies for these defects on the basis of present practice.

Centrifugal Castings. A. R. Parkes. (Foundry Trade Journal, 1939, vol. 60, Apr. 13, pp. 310, 318). The author describes briefly the theory and practice of centrifugal casting with special reference to the manufacture of cylinder liners and piston rings.

Experience and Test Results with a Centrifugal Cleaning Machine and Its Economy in the Steel, Malleable-Iron and Grey-Iron Foundry. V. Unger. (Giesserei, 1939, vol. 26, May 5, pp. 223–229). After a general review of the plant for cleaning castings, the author describes the development of a machine in which a revolving wheel with two blades throws the sand against the casting by centrifugal force. No compressed air is required and the cost of electric power for the new machine is about one-sixth of that required to produce compressed air for sand-blasting equipment. From a detailed comparison of the costs of the two processes the author shows that the centrifugal machine can be used for cleaning steel, malleable iron and grey iron castings at about half the cost of the sand-blast process. A machine of the type described has given over two years satisfactory service.

New Foundry for Pipe Specials. (Foundry Trade Journal, 1939, vol. 60, May 4, p. 363). A brief illustrated description is given of a recently completed addition to the foundry plant of The Stanton Ironworks Co., Ltd. This provides for the mass production of special pipe castings up to 12 in. in dia. Permanent metal patterns and machined moulding boxes are employed and the moulds are rammed by pneumatic hand rammers. The sand is fed to the machines from overhead hoppers and a modern sand reconditioning plant has been installed.

The Foundries of J. & E. Hall, Limited, Dartford. (Foundry Trade Journal, 1939, vol. 60, Apr. 20, pp. 325–326). A description is given of the foundry and processes employed at the Dartford Works of J. and E. Hall Ltd. a firm now specialising in the production of machinery for refrigeration, lifts and escalators.

Heinrich Ehrhardt and the Rheinische Metallwaaren- und Maschinenfabrik. (Stahl und Eisen, 1939, vol. 59, May 4, pp. 549–550). A brief account is given of the development and present activities of the Rheinmetall-Borsig Aktiengesellschaft which was formed by the amalgamation in 1935 of the Rheinische Metallwaaren- und Maschinenfabrik, Düsseldorf with A. Borsig G.m.b.H., Berlin.

What Causes Scrap Losses. W. G. Reichert. (Foundry, 1939, vol. 67, Apr., pp. 32–33, 88, 90). The author analyses the main causes of rejected castings and suggests some methods of foundry

control which would assist in establishing whether a rejected casting is attributable to the sand, metal, moulding or gating.

Control of the Solidification of Castings by Calculation. N Chvorinov. (Institute of British Foundrymen (International Foundry Congress), London, June 1939, Preprint No. 678). The soundness of castings depends mainly on freezing conditions, adequate feeding being the chief requirement. The mechanical properties of sound cast steel are practically as good as those of forged steel. To attain good feeding, controlled directional solidification should be sought. To obtain such conditions an exact knowledge of the laws of solidification is necessary. The author formulates the relationships of solidification which can be used to calculate the solidification periods of practically any casting. The relationship between the solidification period and the thermal properties of a moulding material is given. This formula can be applied to calculate the solidification periods of any metal cast in moulds of any thermal properties. A means of quantitative calculation is thus available by which the directional solidification can be predicted.

Porosity and Sinking in Cast Iron. W. West and C. C. Hodgson. (Foundry Trade Journal, 1939, vol. 60, Apr. 20, pp. 329–333; Apr. 27, pp. 344–346; May 4, pp. 364–365). The authors refer to the work of the British Cast Iron Research Association on treating molten iron so as to cause the graphite to be distributed throughout the mass of a casting in the very finest form, and they describe their own experiments with the object of applying this technique so as to eliminate or reduce porosity and external sinking of castings. The first part of their experiments consisted of examining and comparing the casting conditions, structure and mechanical properties of two sound and one faulty castings (a pump body weighing 10 lb.) made from the same pattern. The microscopic examination revealed that the chief differences between the sound and the unsound castings were the size of the graphite flakes and the distribution of the phosphide. They next examined the relationship between the properties of the metal and its soundness by mechanical tests on the castings and on test bars and by using shrinkage spheres 3 in. in dia. joined by a runner $\frac{1}{2}$ in. in dia. moulded in green sand; these are similar to those used by the above Association and they may be regarded as castings for which no provision has been made for feeding. The authors present the results of the tests on the shrinkage spheres in great detail and note in particular that the size of the shrinkage cavity in the sphere increased as the casting temperature was raised. They obtained ample evidence that titanium treatment aids internal soundness but they did not find any clear indication of the influence of such treatment on sinking. In the concluding part of their paper they discuss the relationship between sand and soundness and describe their investigations which led to the conclusion that (*a*) castings made in dried moulds are less susceptible to external sinking than those made in green sand, and (*b*) provided that the moulds are

dried, the composition of the sand does not seem to be of importance in relation to the phenomenon of sinking.

Foundry Education and Training in Great Britain. J. G. Pearce. (Institute of British Foundrymen (International Foundry Congress), London, June, 1939, Preprint No. 686). The author commences with a brief outline of recent changes and developments in education which affect entrants to the foundry industry, and then devotes the major part of his paper to the present provision for the technical training of the operative or craftsman, the intermediate technical grades and the executive and higher technical grades. In conclusion he gives some information respecting the British Foundry School which started in 1935.

PRODUCTION OF STEEL

(Continued from pp. 13 A–17 A)

The Richard Thomas Ebbw Vale Works. (Engineer, 1939, vol. 167, Apr. 28, pp. 525–528; May 5, pp. 556–559; May 12, pp. 588–590: Colliery Guardian, 1939, vol. 158, Apr. 28, pp. 737–741; May 5, pp. 788–791: Engineering, 1939, vol. 147, Apr. 28, pp. 489–494: Iron and Coal Trades Review, 1939, vol. 138, Apr. 28, pp. 729–737). **Ebbw Vale Re-Awakes.** (Iron and Steel, 1939, vol. 12, May, pp. 413–424). **A New Era in Continuous Rolling.** (Sheet Metal Industries, 1939, vol. 13, May, pp. 611–622). A descriptive account with numerous illustrations is presented of the lay-out and plant of the Ebbw Vale Iron and Steelworks of Richard Thomas and Co., Ltd. The plant includes two blast-furnaces, three open-hearth furnaces, three Bessemer converters and one mixer, with a productive capacity of 9000 tons of steel per week. There are also rolling mills including a continuous strip mill, and a complete coke-oven and by-product plant handling 1000 tons of coke per day.

Well-Known British Steelmaking Firms—No. 2. Hadfields Ltd. (British Steelmaker, 1939, vol. 5, Apr., pp. 148–150). A brief account of the history, present plant and products of the Sheffield firm of Hadfields Ltd., is presented.

Two New Steel Works for South Africa. (Engineer, 1939, vol. 167, May 5, p. 569). Some information is given respecting a new steelworks which is to be erected at Vereeniging about 50 miles from Johannesburg. The first lay-out on the 300-acre site is expected to have one blast-furnace with steel plant, rolling mills and allied machinery, and it will exploit the low-grade ores from Thabazimbi in the Rustenburg district. Another new steelworks belonging to The Rhodesian Iron and Steel Corporation Ltd., has recently been opened at Bulawayo. The plant at this works comprises: one Héroult electric furnace, one 5-ton steam hammer, one 10-in. and one 12-in. rolling mill and one 15-cwt. Massey drop stamp. A complete steel foundry for the manufacture of all classes of castings up to 5 tons is in course of construction.

Port Kembla's New 175-Ton Open-Hearth Furnace. R. Knight. (Blast Furnace and Steel Plant, 1939, vol. 27, Apr., pp. 355–356). The author presents a brief description of a new steel furnace at the Kembla Works of Australian Iron and Steel Ltd. It has a capacity of 175 tons, is built with a sloping back wall and is specially designed to burn tar atomised by superheated steam and coke-oven gas.

The Acid Bessemer Process of Steel-Making. T. Swinden and F. B. Cawley. (Iron and Steel, 1939, vol. 12, Apr., pp. 387–391; May, pp. 431–434). The authors describe the acid Bessemer plant

and process as worked by the Workington Iron and Steel Co. This article appeared in Iron and Coal Trades Review, 1939, vol. 138, Mar. 17, pp. 502–503; Mar. 24, pp. 547–548. (*See* Journ. I. and S.I., 1939, No. I., p. 342 A).

Some Observations of the Precipitation of Ferrous Oxide. F. Kanz and E. Scheil. (Archiv für das Eisenhüttenwesen, 1939, vol. 12, Apr., pp. 481–484). The authors report on their investigation with the microscope of the transformation expressed by the equation

$$4FeO \rightleftharpoons Fe + Fe_3O_4$$

which occurs in the formation of pure ferrous oxide and in basic Bessemer slags high in ferrous oxide. Their observations confirmed those of G. Chaudron and H. Forestier made by magnetic methods.

An Experimental Open-Hearth Furnace. H. K. Work and M. H. Banta. (Metal Progress, 1939, vol. 35, May, pp. 479–483). The authors describe the experimental steel furnace installed by the Research and Development Division of the Jones and Laughlin Steel Corporation. This furnace is of 1 ton capacity, the bath at the slag line is 4 ft. 6 in. square with a maximum depth of 12 in., the hearth is lined with magnesite and there is a large slag pocket between the exhaust port and the recuperator. It is fired by natural gas from three burners designed to provide short flames, and the air to the burners is preheated by the recuperator which consists of two horizontal banks of 18 carborundum tubes each. The authors describe the charging and melting practice and state that the physical properties of the steel produced from this furnace are similar to those produced by the full-scale furnaces; they are therefore satisfied that experience obtained from this small furnace can be applied to full-scale production.

On Open-Hearth Furnaces. J. Carmann. (Berg- und Hüttenmännische Monatshefte der Montanistischen Hochschule in Leoben, 1939, vol. 87, Mar., pp. 49–58). The author discusses the design and operation of German basic open-hearth furnaces with particular reference to points which experience has shown can lead to increased efficiency. He considers the subject under the three headings: (1) Increasing the amount of heat supplied per hour by using fuels of higher calorific value; (2) increasing the quantity of the same fuel used per hour; and (3) obtaining greater heat utilisation by preheating to a higher temperature and by using the gas more efficiently. He stresses the increased life of furnace roofs obtained by using chrome-magnesite bricks instead of silica bricks.

Investigation of Open-Hearth Furnaces with the Object of Improving their Construction. N. Dobrokhotov, G. Lukhnarevich and A. Lukashkov. (Stal, 1938, No. 8–9, pp. 14–23). (In Russian). The investigation was carried out on a model one-twentieth the size of a 250-ton open-hearth furnace. The design of the gas-inlet port, the flow of the gases into and through the furnaces, their impact on the back wall of the furnace and the exhaust port as well as the

effect of both ports on the direction of the gas flow were considered. The flow of the gas stream, the separation and deposition of solid matter in slag pockets of different design were examined using models, and the operation of regenerators was studied in the same way. A uniformly oxidising atmosphere throughout the furnace and improved conditions for combustion were obtained in the case of Venturi ports by supplying more air to the vertical duct near the front wall than into the duct near the back wall. An increase in width of the working space, other conditions being equal, has a favourable effect on the life of the roof and wall. The slag pockets function mainly by the sticking of the slag particles to the walls, and improved separation of slag from the products of combustion can be obtained by producing turbulence and reversals in the gas flow. In regenerators the distribution of the gases through the interior is markedly affected by the shape and size of the inlet openings.

Trial Operation of a 150-Ton Open-Hearth Furnace According to a Schedule. E. Vyatkin and D. Loginov. (Stal, 1938, No. 8–9, pp. 23–38). (In Russian). The causes of the deviations from schedule of open-hearth heats are presented. These include deviations during the preparatory charging period as well as deviations from the required heat supply during melting. In the first heats the time taken may differ by as much as 5% from that required by the schedule. By a more exact rate of heat supply, by using a standardised air consumption curve and even by a partial control of the boil the deviations in the duration of the heats may easily be reduced to $\pm$30 min.

The Production of Slightly Ageing Steel *MS*. M. Gershgorn and R. Popov. (Stal, 1938, No. 8–9, pp. 31–38). (In Russian). Full details of two heats of *MS* steel (carbon 0·15–0·25%, manganese 1·2–1·6%, silicon 0·2–0·4%, copper 0·3–0·4%), including metal and slag analyses at various stages, are given. The object of the investigation was to determine whether production conditions could be so chosen that *MS* steel could be obtained with properties equal to those of the low alloy *DS* steel (chromium 0·4–0·6%, copper 0·5–0·7%, manganese 0·7–1·0%). The *MS* steel obtained was subjected to the usual mechanical tests, to artificial ageing and grain size tests and to microstructural examination. The investigation brought out the decisive effect of deoxidisers on the mechanical properties of *MS* steel for which the required values can be obtained by the use of ferro-aluminium and *AMS* (iron-manganese-silicon-aluminium) deoxidisers. The production of these is briefly described. Fine grain size can be obtained by the addition of aluminium in the mould. For maximum mechanical properties (tensile strength 59·5 kg. per sq. mm., yield point 37·0 kg. per sq. mm., elongation 20·4%, reduction in area 67·4%), the carbon content should preferably be 0·19–0·23%, the manganese 1·25–1·45%, while the contents of silicon and copper should be equal to the upper limiting values given above.

Observations on Electric-Melting Practice in the United States. A. G. Robiette. (Metal Treatment, 1939, vol. 5, Spring Issue, pp. 29–33, 47). In the course of visits to some American steel-melting shops where electric furnaces are used the author noted that the three-phase direct arc furnace is the one which finds most favour, and that the Americans prefer electric motor controlled electrodes to the use of hydraulic rams. He found that there were a large number of small or medium plants using basic-lined electric furnaces of 5–15 tons for manufacturing ingots for billets. The process is a single slag operation and a fairly violent boil is favoured; the silicon, carbon and phosphorus are almost completely removed, and some sulphur, up to 20% of that present, is eliminated, even though the slag is oxidising. The steel is partially killed in the furnace by ferro-silicon and/or silicon-manganese additions, the remainder of the deoxidisers being added in the ladle. He observed that the ingots with the best surface were made in iron moulds made by the Randrupson cement moulding process and these moulds retained their surface much longer than those made by the usual sand-moulding process.

In the steel foundry most of the furnaces are acid-lined and in American practice it is considered necessary to create an active boiling so as to remove all residual silicon which has a tendency to absorb gas. In the manufacture of tool steel the induction furnace is considered better than the arc furnace for small production. The author also quotes data on the power consumption and output of electric furnaces used for the production of grey and malleable iron.

Alloy Steel Manufacture. H. C. Bigge. (Canadian Metals and Metallurgical Industries, 1939, vol. 2, Mar., pp. 54–56). The author traces briefly the history of the development of the electric furnace for steel making and then points out the differences between basic open-hearth and basic electric furnace operation. In conclusion he describes the operation of an electric furnace during the oxidising and reducing periods.

New Melt Shop. (Steel, 1939, vol. 104, May 8, pp. 50–52, 76). A brief description is given of a new 30-ton Heroult electric furnace recently installed by The Rotary Electric Steel Co. of Detroit. An unusual feature of this furnace is that 15–20% more cold scrap can be charged than is usually the case; this is possible by virtue of its "expanded top," (the diameter of the furnace up to the floor level is 15 ft. 8 in., above this level the diameter increases to 18 ft. 8 in. at the top). The roof of the furnace has a life of about 100 heats, whilst the refractory lining of the walls lasts somewhat longer.

The Influence of Inspection upon Subsequent Production. W. M. Gladwin. (Iron and Steel, 1939, vol. 12, Mar., pp. 343–347; Apr., pp. 381–382). The author, whose duty it is to record and investigate complaints submitted to a steelworks, surveys the more common defects, showing how they vary according to the form of the product,

i.e., ingots, billets, strip, &c. In the first part he considers ghost lines in ingots, " clinking " and defects in various rolled products. By " clinking " is meant the cracking of an ingot internally during heating prior to forging; it occurs in ingots containing minimum 0·40% of carbon. It is the author's experience that with regard to ingots and billets 75% of the complaints received concern the manufacture of the steel and 25% concern the manipulation, whereas with sections they are equally divided between the manufacture and the manipulation. In the second part of the paper the author discusses defects in cold-rolled strip due to non-metallic inclusions. He also presents tables showing an analysis of the causes of material rejected as a result of (*a*) complaints by customers, and (*b*) inspection by the producer's staff.

The Occurrence, Origin and Detection of Flaws and Defects in Steel. E. Gregory. (Engineering Inspection, 1939, vol. 5, Jan.–Mar., pp. 4–14). The author considers the following flaws and defects which have their origin in the actual steelmaking process and in the ingots: (*a*) segregation; (*b*) blowholes; (*c*) non-metallic inclusions; (*d*) rokes and cracks; (*e*) spelliness (surface flakes due to splashes of steel solidifying on the ingot-mould wall as the mould is being filled); (*f*) pipe; (*g*) double skins and laps; (*h*) corner weakness; and (*i*) inclusion of oxygen.

REHEATING FURNACES

Edgar Thomson's Modern Soaking Pits. (Iron Age, 1939, vol. 143, Mar. 2, pp. 42–43). A brief description with four illustrations is presented of the new soaking pits installed at the Edgar Thomson Works of the Carnegie-Illinois Steel Corporation. There are 11 pits each measuring 15 ft. × 16 ft. × 8 ft. 4 in. deep with 64 recuperators 6 ft. 9 in. × 6 ft. 9 in. × 7 ft. 1½ in. deep. There is a control panel for each pit, and each panel carries two temperature controllers which adjust the air for combustion, a combustion controller which adjusts the fuel-gas composition and a furnace pressure regulator.

Soaking Pit Heating Rates for Cold Ingots. M. J. Conway. (Iron and Steel Engineer, 1939, vol. 16, Mar., pp. 15–16). The author discusses the rate of heating steel ingots in soaking pits and is of the opinion that too little consideration is given to the ability of steel to absorb heat. He describes the procedure adopted at the works with which he is connected and sums this up in the following simple rules: (1) The rate of heating adopted to bring a cold ingot up to 2350° F. is about 30 min. per in. of ingot thickness; (2) the furnace atmosphere is controlled as closely as possible; (3) if there are delays at the rolling mill, the ingot should be held below the rolling temperature; and (4) the fuel should be as low in sulphur as possible.

Steel Mill Furnaces—I. Furnaces for Bars. M. H. Mawhinney. (Industrial Heating, 1939, vol. 6, Jan., pp. 38–44; Feb., pp. 134–142; Mar., pp. 230–234). In Section I. of this part the author outlines the development of recuperative and regenerative soaking pits and describes some installations of both these types at American steelworks. In Section II. he discusses recent improvements in the design of continuous and batch furnaces for billets. In Section III. the author describes some examples of four kinds of heat-treatment furnaces, namely, pit furnaces, car or bogie furnaces, batch and continuous furnaces.

Control of Slab-Heating Furnaces at Irvin Works. (Blast Furnace and Steel Plant, 1939, vol. 27, Mar., pp. 275–276). An account is given of the system of heating control employed on the slab-heating furnaces at the new Irvin Works of the Carnegie-Illinois Steel Corporation. Three furnaces are used and they are heated with coke-oven gas. The attendant at the control panel adjusts the rate of the gas flow to the top and bottom zones and Hagan gas-air ratio regulators automatically adjust the air flow to the same zones. The gas flow to the soaking zone is automatically regulated by electrical impulses received from the soaking-zone potentiometer recorder.

Heating Rounds for Piercing. G. R. McDermott. (Steel, 1939, vol. 104, Apr. 24, pp. 44–46, 69). The author describes a furnace and soaking hearth installed by the Youngstown Sheet and Tube Co. for heating billets prior to piercing for the production of seamless tubes. There are two units, each 86 ft. long by 25 ft. wide designed to heat 50 tons of billets per hr. Producer gas is burned in the top main heating and the soaking zones, and natural gas is used in the under-firing zone. The billets are moved through the furnace on a " walking-beam " mechanism operated hydraulically.

Heating for Forgings. T. A. Lewis. (Iron and Steel Engineer, 1939, vol. 16, Mar., pp. 19–21). The author discusses the heating of steel forgings under the following four headings : (1) The heating rates and temperatures ; (2) the fuel consumption in B.Th.U. per ton of steel ; (3) the furnace atmosphere and the condition of the surface of the forging ; and (4) the furnaces and furnace equipment.

FORGING, STAMPING AND DRAWING

Large Steel Forgings—Notes on Modern Manufacture. A. O. Schaefer. (Metal Progress, 1939, vol. 35, Mar., pp. 237–243). After describing in general terms the heating and forging of heavy solid and hollow forgings, the author discusses their heat treatment, visual examination for defects and the best positions from which to take test pieces.

Contribution to the Determination and Improvement of the Capacity of a Drawing Shop by Calculation of the Controlling Factors. H. Stevens. (Archiv für das Eisenhüttenwesen, 1939, vol. 12, Mar., pp. 465–471). In this discussion the author explains a method of determining the productive capacity of a drawing shop making round, square and hexagonal steel bars up to 40 mm. in section, and shows what steps should be taken in order to increase the production.

The Formation of Contoured Sheet Metals by Stretching. (Engineering, 1939, vol. 147, May 5, pp. 526–527). An account is given of a method of manufacturing sheet metal parts with complicated contours such as motor-car bodies, aeroplane fuselages and wings and guards for moving machinery. This method has been developed so as to secure the advantages of rapid, uniform and accurate production characteristic of hydraulic pressing without having to sink capital in a large stock of blocks and dies. The method consists of stretching the metal over wooden formers or patterns, and the stretching machine consists essentially of one or more hydraulic rams and suitable hand-operated jaws for gripping the sheet metal. A number of stretching machines made by L. Schuler A.-G. are illustrated.

Automotive Valves. (Steel, 1939, vol. 104, May 1, pp. 56–57). A brief illustrated description is given of the method of making valves for Chevrolet automobiles. The valves are made from a short piece of sil-chrome steel by an extrusion process. The inlet valves are made from steel containing silicon 3·6–4·2% and chromium 1·85–2·50% whilst the exhaust-valve steel contains 8–10% of chromium.

Wire-Drawing and Strip-Rolling Equipment. (Engineer, 1939, vol. 167, Mar. 31, p. 415). A brief description is given of two wire-drawing machines manufactured by Sir James Farmer Norton and Co., Ltd. These machines are built up from self-contained units, each block being independently driven. One machine is capable of drawing speeds between 450 ft. and 900 ft. per min. The arrangement includes an ingenious device for threading by power or by hand and also means for automatically stopping the machine should the wire break. A four-high cold-rolling strip mill by the same firm

is also described and illustrated. This mill is built up as a unit with a double-reduction totally-enclosed gear-box and a strip-coiling drum. The mill and coiler are driven by a 40 h.p. electric motor.

Theoretical Considerations Involved in Reactive Wire-Drawing. H. A. Stringfellow. (Wire and Wire Products, 1939, vol. 14, May, pp. 253–255). The author presents a mathematical discussion of the stresses which are set up when wire is drawn through a die while a back pull is exerted on it. He comes to the conclusion that in this process the normal and tangential components of the forces acting on and along the surface of the die cone are greatly reduced, thus relieving the heavy shearing stresses which are their normal concomitant; in addition, couples are produced whose direction of rotation is opposite to the direction of travel of the wire through the die and these act on each crystal grain throughout the cross-section of the wire, with the exception of those lying at the neutral axis. The couples reorient the crystal grains by rotation backward, and the resulting orientation in the reduced wire is the result of a combined forward displacement and backward rotation, instead of simple forward displacement at the centre and backward displacement at the surface.

The History of Diamond Dies for Wire-Drawing. P. Grodzinski. (Wire Industry, 1939, vol. 6, Mar., p. 191). The author gives a brief account of his investigations of the history of wire-drawing. The oldest wires found are in Egypt, but it is believed these were produced by a hammering process. In 1332 wire-drawers are first recorded in Frankfurt-am-Main, but the author believes non-metallic drawing dies were first used in the Besançon and Lyons district. He also mentions De Beaufré, a Swiss, who invented improved watch bearings consisting of drilled precious stones, and an English patent granted to Brockedon in 1819 for drilled precious stones to be used for dies.

Barbed Wire. J. André. (Ingénieurs Arts et Métiers, 1938, vol. 92, Sept., pp. 98–100; 1939, vol. 93, Feb., pp. 31–33). In this series of articles the author describes the process of manufacturing barbed wire employed at a French works. In Part I. he deals with the manufacture of the type known as "Yowa" or "Génie Militaire" which has four-point barbs spaced at intervals of 70 mm. He describes the rolling of the wire from rods 50 mm. × 50 mm. × 9 m. long, the pickling, the recovery of iron sulphate from the pickling liquor and the wire-drawing, giving particulars of the consumption of acid and electric power. In Part II. he describes briefly the process of wire-drawing and the machine used for wrapping the barbs in the manufacture of "Yowa" barbed wire.

ROLLING-MILL PRACTICE

(Continued from pp. 18 A–19 A)

Spreading of Steel During Rolling with High Degrees of Reduction. I. M. Pavlov and N. S. Ivanov. (Metallurg, 1938, No. 10, pp. 47–55). (In Russian). By rolling wedge-shaped specimens of steel (carbon 0·4%, manganese 0·68%, silicon 0·26%), the behaviour of the metal at deformations of up to 85% per pass at temperatures of 800°, 850°, 950°, 1000°, 1100° and 1150° C., were studied. The figures obtained show that although the absolute increase in width naturally increases up to the highest deformations (above 60%) its value relative to the absolute reduction in thickness (the coefficient of spreading) falls off markedly at deformations above 50–60%. Up to these deformations, the coefficient of spreading increases with the degree of deformation. The coefficient may exceed unity under certain conditions.

Elastic Deformation of Rolling-Mill Rolls. I. M. Pavlov and Ya. S. Gallay. (Metallurg, 1938, No. 10, pp. 68–79). (In Russian). The authors review previous work on the bending of rolls and consider the various expressions arrived at for the magnitude of the elastic deformation. These formulæ are generally too involved for practical use. For practical purposes the authors derive the following expression for the deflection of the rolls :

$$f = \frac{nPl^3}{384 \times E \times I}$$

where P is the pressure, E the modulus of elasticity of the material, l the effective length of the roll between the bearings, I the moment of inertia of the rolls and n a coefficient depending on the ratio of the width of the strip to the length l of the rolls. Using a special apparatus, the measured deflection of the rolls was found to agree to within 5–10% with the results calculated from the above formula. The formula should be useful for calculations in connection with the cambering of rolls.

The Rolling and Calibration of Railway Rails Type *R*-44. M. Galemin. (Stal, 1938, No. 8–9, pp. 42–46). (In Russian). The design of the nine passes used in rolling down the blooms of 200 × 180 mm. in cross-section and 8–10 m. long to the finished rail are described and illustrated by diagrams. Reference is made to repair of the worn steel rolls by surfacing using the welding process.

The Strength of Rolls and Shafts in Relation to the Design of Fillet. W. Morgenbrod. (Stahl und Eisen, 1939, vol. 59, Apr. 27, pp. 511–514). In a mathematical discussion the author explains a new design of fillet the profile of which is partly straight and partly

the circumference of a circle. This fillet has improved strength properties as compared with those of a simple curved fillet. The design is intended for use in rolling-mill rolls.

Rolls and the User. (British Steelmaker, 1939, vol. 5, Apr., pp. 133–137). Some troubles experienced in service with forged alloy steel rolls are enumerated and illustrated in a series of fourteen photographs. The necessity of close co-operation between the technical staff of the mill and the roll-maker is stressed.

Controlled Production in Sheet-Rolling Mills. L. Liberman. (Stal, 1938, No. 8–9, pp. 5–16). (In Russian). Following an analysis of factors affecting production in sheet mills, the question of maximum output capacity of the mill is considered and a controlled rolling schedule based essentially on the amount of reduction is outlined. This schedule must, of course, fit in suitably with the preheating of the sheet bars and other accessory processes. The necessary control for such a rationalised method of production and its introduction at a works are dealt with. The article contains data obtained from practical experience at the Lenin works.

Further Developments in the Rolling of Wide Strip. B. Quast. (Iron and Steel, 1939, vol. 12, Apr., pp. 383–386). An English translation of an article in Stahl und Eisen, 1938, vol. 58, Dec. 15, pp. 1432–1434, in which the author describes the semi-continuous rolling of wide strip. (*See* Journ. I. and S.I., 1939, No. I., p. 157 A).

Richard Thomas & Co., Ltd.—Continuous Hot Strip Mill. (British Steelmaker, 1939, vol. 5, May, pp. 169–174 : Canadian Metals and Metallurgical Industries, 1939, vol. 2, Mar., pp. 51–53, 56). Following a brief outline of the history of steel-making at Ebbw Vale, an illustrated description of the new hot strip mill of Richard Thomas and Co., Ltd. is presented.

Under the Surface at Ebbw Vale. T. J. Kauffeld. (Sheet Metal Industries, 1939, vol. 13, May, pp. 623–630). The author describes some of the auxiliary equipment of new strip mills of Richard Thomas and Co., Ltd., at Ebbw Vale. A great deal of this equipment is underground and is therefore not usually seen by the visitor. The plant described includes the systems for lubrication, hydraulic descaling, roll contour control, internal cooling of rolls and palm oil distribution.

84-Inch Cold Mill. (Steel, 1939, vol. 104, Apr. 10, pp. 56–60). An illustrated description is given of the new mill for the cold reduction and finishing of steel strip and sheets up to $\frac{1}{4}$ in. in thickness at the Irvin Works of the Carnegie-Illinois Steel Corporation.

Youngstown Sheet and Tube Company Expands Seamless Facilities. T. J. Ess. (Iron and Steel Engineer, 1939, vol. 16, Apr., pp. 2 Y–11 Y). The author describes, with numerous illustrations, the furnaces and tube mills at the works of the Youngstown Sheet and Tube Company.

PYROMETRY

Reducing the Rejected Material in Melting Practice by Using the "Bioptix" Colour-Pyrometer to Measure Radiation. G. Naeser. (Stahl und Eisen, 1939, vol. 59, May 18, pp. 592–598). The author studied the relationships between changes in temperature and changes in amount and intensity of the radiation emitted from the surface of molten steel using the "Bioptix" pyrometer. With this instrument both the true temperature and the coefficient of emissivity can be determined simultaneously. (*See* Journ. I. and S.I., 1936, No. II., p. 23 A). He found that the main causes of the "darkening" in radiation from molten steel are inclusions and oxide layers. Reflection measurements from polished steel surfaces showed that manganese sulphide inclusions "darken" the rays whilst alumina has almost no effect. Radiation measurements on an actively boiling steel bath in an induction furnace led to the following conclusions: (1) Certain very small concentrations of aluminium and silicon showed minimum radiation values; and (2) in low-carbon steels, chromium and manganese always caused darkening. He also conducted some experiments to ascertain the effect of the viscosity of the slag upon the radiation; these showed that the almost "black" radiation from a bath of 2%-chromium steel was made very bright by the addition of a little silicon, but aluminium did not affect the radiation. The author's conclusions are in good agreement with those of K. Guthmann, and they also show that the data obtained by this technique of radiation analysis are particularly useful in that they show the presence or absence of those elements which have so important an effect upon the mechanical properties of the solidified steel. The author concludes by observing that, as the technique provides a means of determining what is going on in the bath before casting, it enables any necessary corrective measures to be taken in good time, thus reducing the number of rejections.

On Metallic Materials for Thermocouples. A. Schulze. (Metallwirtschaft, 1939, vol. 18, Mar. 24, pp. 249–254; Mar. 31, pp. 271–276; Apr. 14, pp. 315–320). After explaining the principles to apply in the selection of suitable metals for thermocouples for temperature measurements in different industrial processes, the author surveys the thermo-electric properties of the noble metals and their alloys with special reference to the important progress made recently in this science. He reproduces the millivolt-temperature graphs for a large number of thermocouples and makes recommendations as to suitable materials for sheaths. In conclusion he discusses the use of thermocouples for the indirect measurement of temperature by radiation.

HEAT TREATMENT

(Continued from pp. 20 A–22 A)

A Continuous Gas-Carburising Process. (Machinery, 1939, vol. 54, Apr. 27, pp. 105–106). An illustrated description is given of the furnace and technique for gas-carburising steel parts which have been developed in America and are known as the Eutectrol continuous process. In this process the work is loaded on alloy steel grids or trays, properly spaced by supports to allow gas circulation around the surface to be carburised. The tray is passed into a muffle which is heated by burners above and below it. The system of gas-tight doors and arrangements for quenching are also described in detail.

Carburizing To-Day. G. T. Williams. (Iron Age, 1939, vol. 143, May 4, pp. 33–38; May 11, pp. 38–41). In these two articles the author surveys modern methods of case-hardening steel. He discusses first the characteristics of the case and the two phases of absorption and diffusion of the carbon in the steel. He considers next the use of solid, liquid and gaseous carburising media and reasons for the selection of one of these for specific purposes. In the second part the author deals with the factors governing the selection of case depth for particular applications and the selection of types of steel for carburising.

Carbide Formation in Cementation. A. L. Nemchinskiy and V. A. Delle. (Metallurg, 1938, No. 12, pp. 55–60). (In Russian). Experiments on the cementation (in carbon + 40% $BaCO_3$ mixture at 500°, 900° and 1000° C. for 5, 10, 20 and 50 hr.) of a carbon and a chromium-nickel steel, in the form of thin plates, followed by chemical analysis and microscopic examination showed that carburisation is not limited by the *ES* equilibrium line of the iron-carbon diagram, but proceeds further, leading to the formation of carbide. This was also confirmed in the cementation under ordinary conditions of 40-mm. dia. cylindrical specimens of the above steel. The presence of " carbide-forming " elements is not essential for carbide formation. Carbide formation may in some cases be slower at high than at low temperatures, owing to the retarding effect of the carbide network formed at high temperatures on the diffusion of carbon into the interior of the austenite grains. The addition of chromium favours spheroidisation of the carbides and thus causes more rapid carbide formation, as compared with that in plain carbon steel.

Case-Hardening Steels for Oil-Production Tools. H. W. McQuaid. (Metal Progress, 1939, vol. 35, May, pp. 471–475). The author reviews the case-hardening properties of a number of American steels and considers the reasons governing the selection of a steel for

making drilling bits for oil wells. The review shows that the steel for the most severe service is usually selected from the following types: The high chromium-nickel, the 5% nickel, the 3·5% nickel-molybdenum and the nickel-chromium-molybdenum, the 3·5% nickel-molybdenum steel being probably the most popular.

Surface-Hardening and Hard-Surfacing. C. E. MacQuigg. (Mining and Metallurgy, 1939, vol. 20, Apr., pp. 189–194: Heat Treating and Forging, 1939, vol. 25, Mar., pp. 123–128). The author distinguishes between "surface-hardening," meaning increasing the hardness of the surface of the original metal, and "hard-surfacing" meaning the addition of suitable metallic layers to the original surface. He describes in detail the process and characteristics of flame-hardened surfaces, which comes under the first category, and discusses under the second category the deposition by welding of layers of (*a*) low-alloy steels, (*b*) high-alloy steels, (*c*) non-ferrous alloys, and (*d*) tungsten carbide and borides.

The Superficial Hardening of High-Speed Steel. J. Garland. (Machinery, 1939, vol. 54, May 11, pp. 168–171). The author describes a form of cyanide treatment for increasing the surface hardness of high-speed steel tools such as broaches, drills, form tools, hobs, dies, gauges &c. A sodium cyanide bath at a temperature of 565° C. is used and the tools may, with advantage, be preheated in an electrically-heated air-type furnace to a temperature slightly below that of the bath. The time of immersion in the cyanide depends upon the size and type of tool and the results desired; a few minutes may suffice for very small tools, whilst in other cases an hour or more may be necessary. Tests are now being made to determine whether the same treatment can be applied to cheaper steels and it has already been found that cyanided drills made from 14%-tungsten steel cannot be distinguished in performance from those containing 18% of tungsten.

Nitride Hardening and Special Nitriding Steels. K. Kruse. (Engineering Progress, 1939, vol. 20, Apr., pp. 79–80). The author describes Krupp's process of nitriding in which the parts to be treated are heated in an electric furnace to about 500° C. in an atmosphere of cracked ammonia for a period of 5 to 90 hr. depending upon the depth of case required.

Some Recent Heat-Treatment Furnace Installations. (Metallurgia, 1939, vol. 20, May, pp. 23–30). A review is presented with twenty-three illustrations in which many different kinds of modern heat-treatment furnaces for both ferrous and non-ferrous materials are described.

Controlled Atmospheres in Heat-Treatment Processes. F. W. Haywood. (Metallurgia, 1939, vol. 20, May, pp. 13–19). After discussing in general terms the production and application of protective atmospheres for annealing furnaces in two groups, *viz.*: those containing carbonaceous gases and those which do not, the author describes a portable unit for "cracking" or dissociating

ammonia gas into its constituent elements hydrogen and nitrogen. This " ammonia cracker " has recently been improved by using a patented regenerative ammonia burner by means of which the contaminated atmosphere is regenerated and used over and over again. With this type of plant the cost has been reduced to the order of 9*d*. or 1*s*. per 1000 cu. ft. of recirculated atmosphere. In the remainder of the article the author describes a number of standard heat-treatments such as bright annealing, bright brazing and descaling.

Measurement and Control of Furnace Atmospheres. A. E. Krogh. (Canadian Metals and Metallurgical Industries, 1939, vol. 2, Mar., pp. 58–62, 66). The purpose of controlling the atmosphere in a heat-treatment furnace may be (*a*) to prevent the formation of scale on the steel, (*b*) to prevent carburisation or to deposit carbon as a preliminary step in case-hardening, (*c*) to prevent decarburisation, (*d*) to produce a particular type of furnace, (*e*) to introduce a gas into the metal, *e.g.*, nitrogen for nitrogen hardening, and (*f*) to accomplish some combination of these purposes. After enumerating these purposes the author discusses in what measure they can be achieved in different types of furnace by different combinations of gases. He studies next the characteristics of different gases and gas mixtures showing how these change with time due to unsuspected causes such as leakage of air into the furnace and changes in the humidity of the air used for combustion. He presents N. R. Stansel's equilibrium curves which show the methane/hydrogen, carbon dioxide/carbon monoxide and steam/hydrogen equilibrium ratios for their reactions with iron-carbon alloys saturated with carbon at temperatures from 1100° to 2500° F. The author's study shows that the best practical instrument to use to obtain data for the control of the working of a furnace is one which records changes in the thermal conductivity of the furnace gases. Such instruments are now available, and the author concludes with a short description of how they are used.

The Influence of Small Alloying Additions on the Scaling and Decarburisation of Steel. H. Schrader. (Stahl und Eisen, 1939, vol. 59, Apr. 20, pp. 473–482). The author presents a survey of the work of several investigators on the effects which small additions of a number of alloying elements have upon the scaling and decarburisation of steel. The alloying elements used were aluminium, beryllium, boron, chromium, cobalt, copper, nickel, manganese, molybdenum, phosphorus, silicon, tin, titanium, and tungsten, and the investigations were carried out on specimens annealed for different times, at different temperatures and in different atmospheres. The scaling tests produced results which were in close agreement, but the results of surface-decarburisation tests were frequently contradictory. The author gives possible explanations for the conflicting results.

Some Observations on 18-4-1 High-Speed Steel. J. G. Morrison.

(Iron Age, 1939, vol. 143, Apr. 27, pp. 29–34, 104; May 4, pp. 40–45, 59). The author describes first a system of marking high-speed tool steel used to enable the possible causes of any peculiar behaviour of the steel to be traced. He describes next the heat-treatment characteristics of the tool steel most commonly used which contains tungsten 18%, chromium 4% and vanadium 1% with particular reference to the effect which traces of other elements have upon its properties. In this connection he suggests that manufacturers might, with advantage, determine the amount of iron when making check analyses and if this percentage, when added to those of the above three elements, made a total of less than say 99·5%, that would be evidence of the presence of some impurities which should also be determined. In the second part the author discusses the causes of cold brittleness which is sometimes apparent in 18-4-1 steel, the hardenability and susceptibility to decarburisation of this steel.

Cold Finished Bars. A. G. Sturrock. (Steel, 1939, vol. 104, May 1, pp. 68–70). The author describes a furnace for the heat treatment of alloy-steel bars which are to be machined after heat treatment. A bogie 36 ft. long × 6 ft. wide forms the bottom of the furnace which has a rated annealing capacity of 40,000 lb. per charge. It is heated by fifty low pressure gas burners arranged in two rows along each side, one row being below the charge and the other above it.

Heat Treatment of Fechral. V. Erakhtin. (Stal, 1938, No. 8–9, pp. 71–72). (In Russian). The alloy investigated contained 0·20% of carbon, 0·73% of manganese, 1·06% of silicon, 13·0% of chromium and 3·5% of aluminium. Mechanical tests on wire showed that the optimum intermediate annealing consists of heating to 740–760° C. for 20–30 min., followed by cooling in air. Such a treatment will ensure satisfactory mechanical properties for further drawing, and also for winding the wire into coils for electrical resistance heating elements.

The Heat Treatment of Wire and Wire Products—Modern Annealing Equipment for Wire and Rods. A. T. Greiner. (Wire Industry, 1939, vol. 6, Mar., pp. 183–187). The author describes the furnace equipment used for annealing coils of wire and rods. This consists of a furnace fired with fuel oil or any gaseous fuel, a pre-heating pit and four annealing covers made of rolled heat-resisting alloy-steel sheet. These covers are 3 ft. in dia. by 8 ft. high and the upper and lower ends are fitted into sand seals. He gives particulars of the production, fuel consumption, labour requirements and maintenance. The fuel consumption is 7–9 gal. of fuel oil per ton of steel or not exceeding 1·4 cu. ft. of coke-oven gas per pound of steel. The amount of heat required is therefore about 1,400,000 B.Th.U. per ton of wire.

The Heat Treatment of Wire and Wire Products—Bright Annealing Strip and Wire. J. H. Crossley. (Wire Industry, 1939, vol.

6, Feb., pp. 117, 120). The author describes some annealing furnaces used in the Birmingham district for the bright annealing of strip in straight lengths of 6 to 10 ft. These are usually of the roller-driven-hearth type, and the strip passes first through an electrically heated chamber and then through a water-jacketed chamber, both of which are filled with a special atmosphere.

Full-Annealing of Bar Steel. G. Wallquist and G. Larsson. (Jernkontorets Annaler, 1938, vol. 122, No. 12, pp. 611–646). (In Swedish). After outlining the disadvantages of the batch-annealing process for the full-annealing of steel bars, the authors describe how these have been overcome by the introduction of the continuous process in which the bars pass at a predetermined rate through the furnace the temperature of which is controlled in different zones. They also describe their investigation of the effects of the three annealing factors, temperature, time and rate of cooling, upon the properties of a hypereutectoid steel containing 1% of carbon and 1·5% of chromium. From the data obtained they construct the optimum time–temperature curve, showing that the annealing cycle can be completed in 9 hr. They present the results of hardness tests and microscopical examinations in the form of tables and micrographs. They conclude with a description of a continuous annealing furnace.

The Heat Treatment of Cast Iron by Hardening and Tempering. J. E. Hurst. (Metallurgia, 1939, vol. 20, May, pp. 19–22). The author discusses the theory and practice of hardening and tempering cast iron, illustrating his paper with numerous graphs which demonstrate the effect of different treatments upon the mechanical properties. He concludes by explaining the influence of chemical composition and alloy additions upon the properties of the metal after hardening and tempering.

The Hardening on Tempering of Austenitic Chromium-Nickel Steels Containing Boron. H. Cornelius. (Archiv für das Eisenhüttenwesen, 1939, vol. 12, Apr., pp. 499–505). The author investigates the hardenability of alloy steels containing carbon 0·04–0·33%, chromium 16·2–32·6%, nickel 6·4–30% and boron 0·8–1·7%. He finds that steels containing very little carbon (below about 0·07%) do not precipitation-harden, but, if the carbon is increased while the other elements are kept constant, precipitation-hardness will occur after quenching from high temperatures and tempering at 600–800° C. As the nickel content decreases and the chromium content increases the hardenability decreases. He shows that the austenite is transformed to martensite on tempering boron-bearing steels if the nickel and chromium contents are so adjusted as not greatly to exceed those which would be required to stabilise the austenite in alloys not containing boron.

The Hardening of Rail Ends by High-Frequency Currents. V. Vologdin. (Stal, 1938, No. 8–9, pp. 47–51). (In Russian). The essential features of an induction hardening equipment for the

rapid hardening of the top and sides of the head at the end of a rail are described. Current is supplied from a H.F. generator (2000 cycles, 150 kW.) and is stepped up by means of a suitable transformer directly connected to the induction coil which consists of one or two turns of water-cooled copper tubing. The depth of hardening, which should be about 0·5 cm., can be controlled by varying the frequency. For this depth the energy consumption works out at about 2 kW. for hardening a length of 200 mm. from the ends of the rail. The special shape of the induction coil and the use of a soft iron "magnetic conductor" enable the energy to be concentrated in the head of the rail without at the same time causing overheating of the edges. Hardening by the induction method is much cheaper than by the autogenous process and a very uniform hardened layer of any desired structure can be obtained.

Austempering of *S.A.E.* Alloy Steels Not Always Advantageous. P. Payson and W. Hodapp. (Metal Progress, 1939, vol. 35, Apr., pp. 358–362). The authors discuss the theory of a method of heat treatment called "austempering" in relation to Bain and Davenport's S-curves. "Austempering" consists of quenching plain carbon steel from a temperature well above the critical point into a bath at a temperature between 350° and 600° F. and holding it there until it is completely transformed. They study the effects of this treatment on the subsequent hardness of bars varying from 1 in. to $\frac{1}{4}$ in. in dia. and show that as a general rule the maximum section of steel that can be satisfactorily "austempered" is smaller than the section that can be fully hardened in an oil quench, so that only plain carbon steels of small section can be "austempered." The authors consider next the "austempering" of some *S.A.E.* low-alloy steels and describe experiments in which specimens of these steels 0·394 in. square by 1 in. long were quenched from suitable temperatures in baths at from 800° to 300° F., held for 5, 15, 30 and 60 min. and then finally quenched in water. Hardness tests on these samples showed that all grades were completely transformed in less than 1 hr. at all temperatures from 800° to 300° F. and in most cases in less than 30 min. They next prepared another series of specimens of the same size some of which were oil-quenched and tempered in the conventional way whilst others were "austempered," the temperatures being selected to give a range of hardness from Rockwell C35 to C55; the pieces were then broken on a standard Charpy impact testing machine. The authors reproduce graphs in which the Rockwell hardness numbers are plotted against the impact values; these curves show that in the Rockwell hardness range C44 to C53 the "austempered" steels are definitely superior in toughness. In conclusion the authors state that for alloy steel parts which are to be used with a Rockwell hardness number below about C42, the conventional oil-quenching and tempering is superior to the "austempering" treatment when maximum toughness is required.

WELDING AND CUTTING

(Continued from pp. 23 A–27 A)

Automatic Welding and Automatic Welding Appliances. A. Hanson. (Teknisk Tidskrift, 1939, vol. 69, Apr. 15, Mekanik, pp. 37–48). (In Swedish). After discussing the advantages of automatic electric welding as compared with the manual process, the author describes a number of the welding machines which are now on the market, distinguishing between those in which the machine moves along the seam to be welded and those in which the welding head is stationary and the work moves. He also describes some accessories used for special welding work in automatic machines.

Thermit Welding Processes, Technique and Examples. W. Ahlert. (Zeitschrift des Vereines deutscher Ingenieure, 1939, vol. 83, May 6, pp. 515–518). The author explains the principles and describes the development of the thermit process of welding. He also describes the equipment and materials required and illustrates a number of repairs which have been successfully carried out on material of heavy section by this process.

The Application of Weld-Metal Deposits for Repairs and New Constructions. K. L. Zeyen. (Technische Mitteilungen Krupp, Technische Berichte, 1939, vol. 7, Apr., pp. 15–30). The author presents a detailed discussion of the application of electric welding to repair work, describing in particular the repair of the lips of dredger-buckets, the jaws of crushing machines, boring bits, valves for superheated steam and valves for internal combustion engines.

Contribution to the Knowledge of the Behaviour of Steel St52 on Welding. H. Hauttmann. (Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns, 1939, vol. 7, Apr., pp. 41–47). The author discusses the factors which, in accordance with the present state of knowledge, might contribute to the fracture without deformation of welded structures of German steel St52. He considers that the steelmaker can do little to prevent these fractures, whilst the erector and the welding department can contribute most to its prevention. His discussion deals mainly with the effect of preheating and subsequent heat treatment on the mechanical properties of the welded joint.

The Welding of Alloy Steels. K. L. Zeyen and H. Schottky. (Metallwirtschaft, 1939, vol. 18, Apr. 21, pp. 343–347; Apr. 28, pp. 363–366). The authors describe the technique of welding alloy steels, pointing out where this differs from that employed for ordinary mild steels. They discuss methods of testing joints, the danger of corrosion and how to prevent it and the application of

welding for the purpose of forming corrosion- or wear-resisting coatings on steel.

The Stelliting of Exhaust Valves and Valve Seats. S. A. J. Sage. (Metallurgia, 1939, vol. 19, Apr., pp. 211–214). The author describes the technique of applying stellite (a cobalt-chromium-tungsten alloy) to the surfaces of valves for aero engines, first with the oxy-acetylene torch and secondly by the Wilcox-Rich process. In the latter process a cleaning operation in a flux bath of borax and cryolite is used, and the valve is immersed in a bath of the molten alloy; the thickness of the layer obtained depends upon the number of times the component is immersed and the speed at which it is rotated while in the bath. The author then discusses briefly the heat treatment of stellited parts, pointing out that nickel-chromium austenitic steels, after stelliting, are normalised from 900° C. which removes the strains set up in the parent metal and has very little effect on the grain size. In conclusion he describes the preparation of test specimens by etching and reproduces a number of micrographs showing both good and bad fusion between the parent metal and the stellite.

Oil Well Bits. N. J. Clark. (Steel, 1939, vol. 104, Apr. 17, pp. 76–77). The author describes how tungsten carbide is made from tungsten powder and carbon, and how the carbide is applied to the cutting edges of roller bits used for boring for oil.

Hard Facing of Oil Well Drilling Bits with Cast Tungsten Carbide. C. H. Shapiro. (Metal Progress, 1939, vol. 35, Apr., pp. 363–367). The author describes the technique employed for building up the worn edges of drilling bits for oil boring by depositing first steel with physical properties similar to those of the parent metal and then welding on tungsten carbide inserts, using the oxy-acetylene torch. He also describes the subsequent grinding and heat treatment.

Modern Blast-Furnace Construction. J. Stoecker and A. Rein. (Welding Industry, 1939, vol. 7, May, pp. 126–130). The authors present an account of the welding technique employed in the building of the all-welded blast-furnace of the Bochumer Verein which was reconstructed in 1936. (*See* Journ. I and S.I., 1938, No. II., p. 343 A).

On the Causes of the Tendency to Fissure Formation in Welds in Steel for Aircraft. O. Werner. (Archiv für das Eisenhüttenwesen, 1939, vol. 12, Mar., pp. 449–455). The author investigated the causes of fissure formation in oxy-acetylene welded thin steel sheets used for constructing aeroplanes. He came to the following conclusions: (1) The fissures become visible at about 700° C. in the zone immediately adjacent to the weld; (2) when the carbon content of the steel is kept constant, the fissure-formation tendency increases with increasing sulphur content; (3) the fissure-formation tendency is reduced by increasing the temperature of the bath when the steel is made; (4) the position of the Ar_3 point of the steel appears to

have no definite relationship to the fissure-formation tendency; (5) the tendency to fissure formation is caused by the presence of comparatively small quantities of ferrous and manganous oxides in the steel, for these react with hydrogen from the acetylene to form steam which causes discontinuities in the steel; (6) a similar but weaker effect is brought about by the sulphur in the steel combining with the hydrogen to form sulphuretted hydrogen.

Proposed Specification Relative to Testing the Weldability of Steel for Aeronautical Construction. (Revue de la Soudure Autogène, 1939, vol. 31, Apr., pp. 654–660). The text is published of the regulations proposed by the commission appointed by the Comité de Normalisation de la Soudure to formulate tests for determining the weldability of steel to be used in the construction of French aircraft.

The Effect of Different Kinds of Treatment on the Tensile-Fatigue Strength of Gas-Welded Joints in Boiler Plate. K. H. Bussmann. (Wissenschaftliche Abhandlungen der deutschen Materialprüfungsanstalten, 1939, vol. 1, No. 2, pp. 59–64). The author describes his investigation of the fatigue strength of gas-welded joints in 15-mm. and 30-mm. boiler plates using tensile-fatigue testing machines with periodicities of 375 and 500 per min. The specimens were treated after welding in four different ways, as follows: (1) The weld was hammered while still hot; (2) annealing at 650° C. for 30 min.; (3) annealing at 920° C. for 30 min.; and (4) annealing at 920° C. and grinding the surface in the direction of the weld. The results showed that processes (1) and (4) increased the tensile-fatigue strength more than the others, that process (3) was also beneficial and that the results of process (2) were erratic.

PROPERTIES AND TESTS

(Continued from pp. 32 A–40 A)

Microscopic Investigation of the Deformation under Static and Dynamic Tensile Stressing and During Repeated Bend-Fatigue Tests. K. N. Klimov. (Metallurg, 1938, No. 10, pp. 80–85). (In Russian). The investigation was conducted on test pieces of Armco iron and several carbon steels, and it included microscopic observations during static tensile tests (on flat test pieces), repeated impact tests on an Amsler machine and repeated bend-fatigue tests. The microscopic examination was supplemented in the case of the tensile tests and the repeated bend-fatigue tests by a magnetic method of examination, which was much more accurate than microscopic observation in indicating the commencement of plastic deformation. In addition to the above general observations, a short study was made of the behaviour of slag inclusions (manganese sulphide) during the deformation as a result of the above forms of stressing. In static stressing of mild steels the first slip lines appear at a point corresponding to the end of the horizontal yield portion of the stress-strain diagram. In fatigue tests, slip lines appear only when the load exceeds the experimentally determined fatigue limit. With loads below this limit a system of markings developed in certain grains. These markings when highly magnified have the appearance of small spreading cracks. A definite difference in the development of the plastic deformation of test-pieces with ferrite-austenite, granular pearlite and ferrite-pearlite structures was observed. Under static and dynamic impact tensile stresses manganese sulphide inclusions begin to break up at very low loads and partially fall out leaving voids. Under fatigue stresses whole colonies of manganese sulphide inclusions remain unaffected even when the ferrite between them shows signs of destruction. Under static and dynamic tensile stresses, sulphide inclusions form the starting points from which the slip lines develop. This behaviour is not observed in test-pieces subjected to fatigue stresses.

The Plastic Flow of Metals. C. W. MacGregor. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1036 : Metals Technology, 1939, vol. 6, Apr.). The author describes an apparatus he devised for obtaining photographic records of the plastic flow in steel as revealed by Lüders lines. This apparatus, called a plastiscope, possesses some advantages over that designed by A. Nádai and the author a few years ago because it can be used (*a*) to project the image of tested specimens on to a lecture-room screen at large magnification ; (*b*) to take still photo-

graphs at small or large magnification; (*c*) to reveal the plastic flow of the steel continuously as it occurs during testing; (*d*) to show the plastic flow in such processes as rolling; and (*e*) to take motion pictures of the process of plastic flow. Several photographs taken with the apparatus are reproduced.

Fatigue in Structural Steel Plates with Riveted or Welded Joints. B. P. Haigh and T. S. Robertson. (Engineering, 1939, vol. 147, Apr. 14, pp. 451–453; Apr. 28, pp. 513–517). The authors after describing the nature and limits of testing which can be applied with the Haigh electro-magnetic fatigue-testing machine at the Royal Naval College, Greenwich, describe their investigation of fatigue and plastic yield in structural steel and of fatigue in riveted and welded joints in structural steel. From the results of tests on structural steel they conclude that although turned and well-finished test-pieces may give limiting strengths as high as (0 ± 13) tons per sq. in. in 26-ton mild steel, such a result is too high to serve usefully for the guidance of practical men, for in service fatigue cracking necessarily commences under much lower nominal stresses. From the fatigue tests on riveted joints they conclude that, when the rivets are tight enough to resist slip and are of ordinary proportions, fracture occurs by the plate cracking from the ends of the transverse diameter of the rivet hole, and the limiting range of load is relatively low so that high factors of safety are required. Tests on samples of deposited weld-metal indicated that the optimum fatigue-limiting strength of the deposited metal was ($0 \pm 12\frac{1}{2}$) tons per sq. in. which was very little less than the optimum value of (0—14) tons per sq. in. found in well-finished samples of unwelded boiler plate.

Deformation and Fracture of Mild Steel Under Cyclic Stresses in Relation to Crystalline Structure. H. J. Gough and W. A. Wood. (Proceedings of the Institution of Mechanical Engineers, 1939, vol. 141, Apr., pp. 175–185). The paper describes an extension of a recent research into the characteristics of the deformation and fracture of metals under static and fatigue stressing as revealed by precise methods of X-ray diffraction. The four series of fatigue tests were designed specially to take into consideration the cases where the upper stress of the cycle is in the immediate neighbourhood, first, of the ultimate tensile strength, and second, of the static yield point of the material. Accurate records have been made throughout of the changes in shape of the specimen. The structure has been examined by the X-ray method at the end of the test in every case, and also, in certain cases, at various interrupted stages.

The results have shown that, in general, the observed changes in structure, even under the most critical conditions of stress, are similar in nature to those found in the previous work. It has also been established that, under a safe range of stress, the damage to the structure is equivalent to that caused by a single sustained

application of a static stress equal in amount to that of the maximum stress of the cycle. Further, the additional and progressive damage caused by cycles of an unsafe range of stress leads to a complete fragmentation of the whole or part of the specimen. Finally, the results of the complete series of alternating and pulsating direct stresses have been reviewed in relation to the deformation in the specimen; the conclusion is reached that, though complicating factors are present, the *average* stress of the cycle appears to have only a small effect on the fatigue resistance of the material.

A Fatigue Failure with some Unusual Characteristics. D. D. Howat and E. Mitchell. (Iron and Steel, 1939, vol. 12, Apr., pp. 376–380). The authors describe their investigation of the causes of failure of a forged mild steel shaft used for crushing sugar cane. The shaft was 14 ft. long and 18¼ in. in dia. and on it was shrunk a cast iron roller 6 ft. long and 34½ in. in dia. In service the roller ran at 2¼ r.p.m. and at full load the pressure on each journal was 200 tons. The fracture across the shaft occurred inside the roll 20 in. from the journal. Visual examination showed that the crack had grown slowly in the centre and final rupture occurred suddenly in an outside segment of the shaft. The authors subjected specimens to microscopical examination and to mechanical tests. Peculiar ripple-like pitting was observed on a specimen cut from the surface. They concluded this pitting was caused by juices from the cane working their way between the roll and shaft and becoming trapped, and, when the roll shell was pressed up against the shaft as a result of the crushing, the juice would be suddenly ejected, and the repeated surges of the juice out from the space between the roll shell and the shaft would cause this peculiar type of pitting. They considered that the failure was due to a combination of three factors, namely, the uneven grain size throughout the section, the existence of a severely worked outer skin on the shaft and the peculiar corrosion on the surface.

The Application of Surface Pressure by Means of a Steel Shot Blower for the Purpose of Increasing the Fatigue Strength. O. Föppl. (Mitteilungen des Wöhler Instituts, 1939, No. 36, pp. 44–59). The author refers to the American practice of increasing the fatigue strength of a highly stressed part by closing up any surface pores or cracks by spraying the surface with steel shot from a blower. He compares the effects produced by the action of a ball-ended pneumatic hammer with that produced by steel shot from a blower.

Principles of Hardness Testing. E. Skerry. (Engineering Inspection, 1939, vol. 5, Jan.–Mar., pp. 15–17). After defining hardness in steel as its resistance to permanent distortion under pressure, the author discusses the limitations of testing machines which are based on making and measuring ball or pyramid impressions. He mentions some factors which should be taken into account in determining to what extent tests on a few samples may be assumed to be representative of a batch of material, and in conclusion

points out the importance of measuring the diameter rather than the depth of the impression.

The Döhmer Hardness Factor—A Valuable Material Index. P. W. Döhmer. (Zeitschrift für Metallkunde, 1939, vol. 31, Jan., pp. 15–16). The author shows by load/impression-diameter curves that the Brinell and Meyer hardness numbers are not constants. He explains how he calculates an " end-hardness factor " from the Brinell number using Meyer's law and shows how this factor gives an indication of the annealed state of a steel as well as of its hardness.

A Wear and Lubricant Testing Machine. (Metal Industry, 1939, vol. 54, Mar. 24, pp. 347–348). The constructional details of a machine developed by The Timken Roller Bearing Co. for testing the load-carrying capacity of lubricants and the wear of materials is described. In this machine a special Timken cup revolves against a test piece and a lubricant is supplied at a predetermined rate and temperature. The test piece is mounted on a system of levers by virtue of which the test piece is always in the same relative position to the revolving cup and the unit load of the length of the cup and the test piece is always constant. This load can be set by sliding a weight along the friction lever. To determine the amount of wear the weight of the test specimen is taken before and after the test.

The Wear of Grey Iron and its Dependence on Outside Circumstances. T. Klingenstein and H. Kopp. (Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns, 1939, vol. 6, Mar., pp. 23–33). After enumerating those factors which are now generally accepted as having an important influence on the wear of cast iron, the authors discuss how the different working conditions of different machine parts retard or accelerate the wear, the effect of different machining processes on the initial surface condition of a part and its subsequent wear, the effect of the size and distribution of the graphite particles and the effect of molecular conditions, the last-named including wear by corrosion, oxidation and pure friction.

Methods of Testing Ferro-Magnetic Materials and the Results. A. Kussmann. (Zeitschrift des Vereines deutscher Ingenieure, 1939, vol. 83, Apr. 22, pp. 445–456). The author examines the recent work of numerous investigators of the magnetic properties of ferrous materials. The results of this work show that the differences in the magnetic permeability and hysteresis characteristics of ferrous materials can now be satisfactorily explained by reference to their crystallographic anisotropy, magnetostriction and internal stresses.

The Thermal Conductivity of High-Duty and Alloy Cast Irons. J. W. Donaldson. (Institute of British Foundrymen (International Foundry Congress), London, June, 1939, Preprint No. 666). The author describes an investigation of the thermal conductivity of a number of plain, alloy, high-duty and heat-

resisting cast irons. The general conclusions may be summarised as follows: (1) The thermal conductivity of grey cast iron is lowered by copper in a similar manner to which it is lowered by silicon and nickel. The influence of copper is, however, approximately half that of silicon. (2) Molybdenum tends to raise the thermal conductivity of grey cast iron, and in this respect acts in a similar manner to chromium and tungsten, although its influence is not so pronounced. (3) Where nickel and chromium, or nickel and manganese, are alloyed together in cast iron, the influence of nickel in lowering the thermal conductivity is counteracted to a slight degree by the chromium or manganese. (4) A large proportion of nickel has a pronounced influence in lowering the thermal conductivity of cast iron, but where part of the nickel is replaced by copper, the influence is not so marked. (5) Aluminium, even in the presence of chromium, has a very pronounced influence in lowering the thermal conductivity of grey cast iron. The analyses of the alloys tested, the temperature ranges and the thermal conductivities are presented in 17 tables.

Growth of Piston Ring Cast Irons. F. Bollenrath and K. Bungardt. (Metal Treatment, 1939, vol. 5, Spring Issue, pp. 21–22, 28). An abridged English translation of an article on the effects of time and temperature of annealing on the growth of iron alloys for manufacturing piston rings. The original article appeared in Stahl und Eisen, 1938, vol. 58, Oct. 13, pp. 1111–1113. (*See* Journ. I. and S.I., 1939, No. I., p. 46 A.)

Fracture of Steels at Elevated Temperatures after Prolonged Loading. R. H. Thielemann and E. R. Parker. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1034: Metals Technology, 1939, vol. 6, Apr.). The authors describe the testing technique developed at the research laboratories of the General Electric Co. for carrying out sustained-load rupture tests on steel specimens at high temperatures. They found that two distinct types of fracture occur, the transcrystalline and the intergranular. In the former, the break occurs through the grains and in the latter, through the grain boundaries. The authors present the results of numerous tests in tables, graphs and micrographs.

Occlusion and Evolution of Hydrogen by Pure Iron. G. A. Moore and D. P. Smith. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1065: Metals Technology, 1939, vol. 6, Apr.). The authors present a critical review and correlate existing information on the occlusion of hydrogen in iron, and describe their own experiments for the purpose of determining the extent to which the conclusions deduced from the review are applicable to iron of really high purity.

Grey Irons *versus* Grey Iron. V. H. Schnee. (Iron Age, 1939, vol. 143, Apr. 20, pp. 19–23, 48). The author compares all the mechanical properties, as well as the machining, welding, wear and

corrosion-resistance properties of two qualities of grey cast iron, one containing about 3·5% of carbon and 2·25% of silicon which represents a soft, common grey iron that has been available for many years, and the other containing about 3% of carbon and 2% of silicon representing a medium high-test grey iron which has only recently become available.

" Ni-Hard " in the Foundry. A. B. Everest. (Foundry Trade Journal, 1939, vol. 60, Apr. 13, pp. 314–316). The author describes the properties of " Ni-Hard," a white cast iron alloy with particular reference to its application for plant within the foundry itself where so much abrasive material is handled. These applications include tumbler end-plates, shot impeller blades, fan blades for pulverised coal, and the deposition on to worn surfaces of a layer of the alloy by electric welding.

Wear-Resisting Alloys. J. E. Hurst. (Iron and Coal Trades Review, 1939, vol. 138, Apr. 14, pp. 658–659 : Foundry Trade Journal, 1939, vol. 60, Apr. 20, pp. 323–324). The author describes the structure and properties of a number of nickel-chromium cast irons of chemical composition between the following limits : Total carbon 2·0–4·0%, silicon 0·25–1·5%, nickel 3·0–7·0% and chromium 0–2·5%. These may be described as high-duty, wear-resisting cast irons and they include those sold under the trade names Ni-Hard, Attritard and *BF*954. Their Brinell hardness lies within the 500–700 range and they possess a tensile strength of about 22 tons per sq. in. The effect of quenching from various temperatures on hardness is shown in a table.

Specially-Hard Alloy Cast Iron for Resistance to Abrasion. M. M. Hallett and A. B. Everest. (Institute of British Foundrymen (International Foundry Congress), London, June, 1939, Preprint No. 665). White cast irons of great hardness and resistance to abrasion have been developed by controlling the structure of the metal by means of alloy additions. An iron of this type is Ni-Hard, which depends on nickel to produce a martensitic structure in the matrix of the castings. The precise alloy content and treatment required to attain maximum hardness vary somewhat with the type of casting produced. The purpose of this paper is to give an account of the mechanism of hardening with a view to assisting the foundryman to secure the best results. The changes which occur during solidification and subsequent cooling of sand cast alloy white iron are described in detail. It is shown that the final hardness of the casting is controlled largely by the temperature range of inversion of the austenite to martensite and the degree to which this change is completed ; this is mainly a function of the carbon content of the austenite. Methods for controlling this carbon content and the effects of alloy elements are described and illustrated by experimental data. Consideration is given to the influence of heat treatment, and recommendations are made for the best procedure for producing various types of castings in the foundry.

Some Applications for Heat-Resisting Nickel Cast Iron. (Metallurgia, 1939, vol. 19, Apr., pp. 235–236). In considering the development of heat-resisting cast iron, it is shown that whilst small additions of nickel alone have no very definite influence on the heat-resisting properties, such additions are, however, of the very greatest importance when used in conjunction with a reduction of silicon or an addition of chromium; in such cases the nickel has a profound influence in eliminating chill, thus improving the machinability and toughening the metal. A form of heat treatment recommended for complicated castings in which a nickel-chromium content is used to give heat-resistance together with pressure tightness and machinability is to anneal the castings before machining at about 600° C. for 1 hr. for each inch of section thickness. Austenitic cast irons containing higher percentages of nickel have also been developed for such service as burner parts, superheater tube spacers and hangers, soot-blower nozzles and Diesel engine parts. Ni-Resist and Nicrosilal are included in this category.

Factors Determining the Mechanical Properties of Russian Malleable Cast Iron. G. N. Troitskiy. (Metallurg, 1938, No. 12, pp. 39–54). (In Russian). The author considers the literature and data from various Russian works at which cupola—and electric-furnace melted—malleable cast irons are produced with reference to the effect of the silicon, manganese, phosphorus, ferrite grain size and degree of dispersion of the temper-carbon on the mechanical properties of the iron. He finds that, within certain limits, changes in the amount of the elements present in the malleable iron have no appreciable effect on the mechanical properties. Refining of the temper-carbon by quenching or rapid (electrical) heating to 900° C. prior to tempering also has no marked effect on the mechanical properties. On the other hand a "natural," as distinct from the above "artificial," increase in the degree of dispersion of the temper-carbon in different heats increased both the tensile strength and the elongation of the iron. This natural refining is ascribed to a fine primary structure. This structure may also influence the properties of the final structure by its effect on the distribution of manganese and silicon in the ferrite matrix obtained on tempering and also as a result of its own partial persistence. In conclusion the author describes his study of the method of influencing the primary structure of the specimens by changing their thickness, as a result of which he concludes that the tensile strength and elongation decrease with increasing diameter, and that the mechanical properties were improved by increasing the temperature and duration of superheating.

Japan's Progress in the Investigation of Iron and Steel Containing Nickel. H. Kikkawa. (Japan Nickel Review, 1939, vol. 7, Apr., pp. 94–119). The author presents a comprehensive review of the work of Japanese investigators during the last ten years on the properties of nickel steels and nickel cast irons. The review shows

that very intensive research of this subject has been carried out, particularly with regard to the magnetic properties.

Stainless and Acid-Resisting Steels, Low in Foreign Alloying Elements, for the Chemical Industry. W. Tofaute. (Technische Mitteilungen Krupp, Technische Berichte, 1939, vol. 7, Apr., pp. 31–35). The author discusses the development in Germany of two classes of alloy steel which are replacing copper, nickel and their alloys in the chemical industry. These are : (1) Low-carbon ferritic chromium- and chromium-molybdenum steels with additions of titanium, tantalum or niobium ; and (2) ferritic-austenitic or purely austenitic chromium-manganese steels.

Valve Steels. A. T. Colwell. (Steel, 1939, vol. 104, Apr. 17, pp. 70–74). The author describes some of the alloys and processes used in the manufacture of exhaust valves for aircraft and automobile engines. He compares the chemical analyses and physical properties of Silcrome No. 1, *XB*, *X*10, and *XCR* steels which are used for this purpose.

Properties of Some Free-Machining, Lead-Bearing Steels. J. H. Nead, C. E. Sims and O. E. Harder. (Metals and Alloys, 1939, vol. 10, Mar., pp. 68–73 ; Apr., pp. 109–114). After reciting evidence that lead in steel is not present in solid solution in appreciable amount but is present in a submicroscopic state of subdivision, the authors present tables in which the mechanical properties of a number of American steels for making bolts, with and without the addition of 0·20–0·25% of lead, are compared. The general inference is that the addition of lead does not lower the mechanical properties, but does markedly improve the machining properties. Provided that the lead content is below the limit of emulsification, there appears to be no segregation of the metal ; in "over-leaded" steels, however, in which agglomerations are present, there is evidence of very slight enrichment of lead in the last portions of the steel to freeze or where advancing crystallisation can entrap unfrozen liquid.

Steel *RF*2 With an Increased Carbon Content. M. Pridantsev and A. Ostapenko. (Stal, 1938, No. 8–9, pp. 73–75). (In Russian). The high-speed steel *RF*2 should contain according to specification carbon 0·71–0·77%, silicon 0·40% max., manganese 0·40% max., chromium 4·1–4·6%, tungsten 11·8–12·8%, and vanadium 2·3–2·6%. The present investigation showed that when the carbon content was increased to 0·85–0·95%, the steel, after quenching from 1250° C. and tempering at 550° C. for 6 hr., had a Rockwell hardness of 64–65 C as compared with 55–59 C for steel of the specified composition.

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 41 A–45 A)

Observing Plastic Deformation with the Microgrid. F. N. Rhines and R. Ward. (Metals and Alloys, 1939, vol. 10, Apr., pp. 129–132). The authors describe a method of studying the deformation of metals using equipment which is commonly available in a metallurgical laboratory, namely a microscope and a sharp-pointed stylus. The specimen to be studied is etched before deformation and a network of squares is scratched on its surface using (in the instance described) the pointed diamond cutter of a scratch-type hardness tester mounted on the table of a microscope; the specimen is moved under the diamond by the mechanical translation gear which moves the table. Under the conditions described the smallest squares which could be produced were about 0·01 mm. Micrographs are then taken of the prepared surface before and after deformation and the plastic flow of the metal can then be studied by comparing these. In conclusion the authors point out that the application of this technique is limited to cases where the deformation is not great enough to obliterate the grid lines, and the flow can only be studied in a two-dimensional external surface.

Contact Prints of Defects Revealed by the Magnetic Testing of Materials. R. Kienzle. (Zeitschrift des Vereines deutscher Ingenieure, 1939, vol. 83, Apr. 29, pp. 483–484). A disadvantage of the magnetic powder method of revealing defects in steel is that no permanent record of a defect can be made for future reference without making use of a photographic process. The author describes a process recently perfected by I. G. Farbenindustrie A.-G., by which a contact print can easily and cheaply be made. The defect having been revealed by a suspension of exceedingly fine iron particles in paraffin, the print is obtained by the application of a sheet of absorbent paper of suitable thickness and texture. The paper soaks up the paraffin and the iron particles are thus drawn into the fibres of the paper where, on the paraffin being dried off, they remain lodged in the same relative density as that which they had when resting on the steel. Any concentrations of particles which revealed the position of a crack thus reproduce similar lines which are easily visible in the absorbent paper.

Cinematography with a High-Temperature Microscope. T. Swinden, T. W. Howie and J. H. Chesters. (Transactions of the British Ceramic Society, 1939, vol. 38, Apr., pp. 245–254). The authors describe a high-temperature microscope equipment which consists essentially of: a furnace with a water-cooled lid and fused-silica window, a metallurgical microscope, a Mikrophot attachment

for simultaneously viewing and filming the subject and a cinematograph camera. They discuss the application of this equipment to the determination of melting points and the study of slag reactions. They use the apparatus to examine the phenomena of "bloating" and dehydration. They obtained records of reactions which occurred at temperatures up to 1600° C.

Electron Diffraction Examination of Metals. M. L. Fuller. (Metals and Alloys, 1939, vol. 10, Mar., pp. 85–89; Apr., pp. 122–125). In the first part of this paper the author describes with the aid of a schematic diagram and photographs the principles and construction of an electron diffraction camera for the examination of the surface of metals. In the second part he describes the method of operation and the preparation of specimens, and reproduces some examples of Debye-Scherrer type patterns from specimens of non-ferrous metals.

Radiography in Iron and Steel Founding. F. W. Rowe. (Institute of British Foundrymen (International Foundry Congress), London, June, 1939, Preprint No. 682). The paper begins by tracing the history of the development of radiology from the studies of Hauksbee in the early part of the eighteenth century up to the present day. The principles of X-ray generation are dealt with, and full details are given of visual inspection by fluoroscopy and radiographic inspection by both X-rays and gamma-rays. The paper is illustrated with views of an up-to-date X-ray installation, showing the method of working, and with radiographs of iron and steel castings of various shapes and dimensions.

Structure of Meteorites. A. J. Bradley. (Nature, 1939, vol. 143, Mar. 25, pp. 518–519). The author refers to the theory recently advanced by E. A. Owen and R. W. Williams in which they account for the Widmanstätten figures in meteorites on the basis of their X-ray studies of both natural and artificial iron-nickel alloys, and discusses the results of his own studies of the iron-rich end of the nickel-iron equilibrium diagram which to a large extent confirm the above theory. From the equilibrium diagram as redrawn as a result of the author's investigation he concludes that a further transformation not mentioned by Owen occurs at about 350° C.

Contribution to the Problem of the Recrystallisation of Steel During Hot-Rolling. I. M. Pavlov and N. S. Ivanov. (Metallurg, 1938, No. 10, pp. 44–47). (In Russian). Previous work by other investigators had shown that there existed a difference between recrystallisation during forging and rolling. In the present investigation wedge-shaped steel (0·4% of carbon, 0·68% of manganese, 0·26% of silicon, 0·07% of chromium) specimens were rolled down in one pass at temperatures of 850°, 950°, 1000°, 1100° and 1150° C. The true deformation was measured by the change in pitch of the screw thread on cylindrical inserts in the specimens. True recrystallisation diagrams (grain size plotted against percentage deformation) are reproduced for temperatures of 850° and 950° C. Raising the

temperature from 850° to 950° C. lowered the critical deformation from 8·3% to 5·4%. At these deformations very sharp lines of demarcation were observed in the rolled specimens. Recrystallisation diagrams for deformation by forging and rolling are not identical, the value of the critical deformation in the latter being somewhat higher.

The Influence of Anisotropy in Sheet Steel 1008 on its Behaviour During Deep-Drawing. G. I. Aksenov. (Metallurg, 1938, No. 10, pp. 96–108). (In Russian). A hot-rolled sheet steel was examined for anisotropy by magnetic tests (by the ballistic method, using a constant field), and subjected to microstructural examination, Erichsen, elongation and deep-drawing tests. The anisotropy, which had an unfavourable effect on the deep-drawing properties, could be reduced practically to zero by normalising.

The Problem of the Critical Rate of Cooling. M. M. Zamyatin. (Metallurg, 1938, No. 12, pp. 29–38). (In Russian). In his discussion on the critical cooling rate of steel the author develops formulæ for the loss of heat from steel specimens based on Newton's law of cooling and Boltzmann's radiation law and points out that it is reasonable to expect that different values for the critical rate of cooling for identical specimens will be obtained, depending on the method of cooling. The results of previous investigators (H. I. French, F. Wever, N. Engel, H. Esse, W. Eilender and E. Spenle) are examined, and the author concludes that the very high values of the critical rate of cooling obtained by the German investigators is due to radiation from the specimens not being taken into account. In conclusion the author traces the relation between the cooling curves (by convection and radiation) and the shape of the curves of the isothermal transformation of austenite. In the case of cooling by convection the critical cooling rate for eutectoid steel at 900° C. is 200° C. per sec. (100° C. per sec. at 720° C.) which is in agreement with the experimental results of H. I. French and O. Z. Klopsch. The corresponding figure in the case of cooling by radiation is 600° C. per sec. at 900° C.

The Influence of Rate of Cooling on the Transformations in Steel. (Metallurgist, 1939, vol. 12, Apr., pp. 18–20). The results of investigations of the influence of different cooling velocities on the transformations in steel carried out at the Kaiser-Wilhelm-Institut, Düsseldorf by F. Wever, A. Rose and H. Lange are correlated (*see* Journ. I. and S.I., 1938, No. I., pp. 41 A, 217 A and 1938, No. II., p. 102 A), and four transformation diagrams of carbon steels for different rates of heating and cooling are presented. These curves show that at the rates employed the undercooling of the pearlite change is practically independent of the carbon content. The Ar_3 transformation is much more strongly undercooled than the Ar_1 change, and pre-eutectoid separation is suppressed before a rate of cooling of 15° C. per sec. is reached. The data of these three investigators are compared in a diagram with the results obtained

by R. F. Mehl and C. Wells (*see* Journ. I. and S.I., 1937, No. II., p. 202 A) in a manner which shows clearly that the rate of transformation in the neighbourhood of the equilibrium temperature must be extremely small. This fact has an important bearing on the interpretation of heating and cooling curves, since these cannot be successfully obtained unless an appreciable difference of temperature exists between the specimen and its surroundings, involving rates of heating or cooling which may amount to 5° C. per min. and so accounting in fairly pure carbon steels for a superheating of 5° or an undercooling of 10° compared with the values which would have been obtained if the temperature had been changing at one-tenth of the rate, *i.e.*, at 0·5° C. per min.

The Dissolution of High-Melting-Point Metals and Alloys in Low-Melting-Point Metals and Alloys. M. G. Oknov and D. Ya. Gluskin. (Metallurg, 1938, No. 12, pp. 7–20). (In Russian). The authors carried out an extensive series of experiments by immersing a sample (about 5 g.) of the high-melting-point alloy or metal supported on an iron wire in about 40 g. of the molten low-melting-point alloy or metal contained in a 25 c.c. graphite crucible, keeping the whole at a definite temperature for a definite time and then allowing to cool. The solidified contents of the crucible were then sawn through and examined microscopically, the nature and position of the products of reaction being noted. The combinations investigated included: iron in aluminium–magnesium, iron in zinc–aluminium, iron and nickel in zinc and iron and nickel in aluminium as well as several combinations of non-ferrous metals. They discuss their observations at considerable length from the phase-diagram point of view and also from the point of view of the heat of formation of intermetallic phases. When high-melting-point pure metals are acted upon by low-melting-point alloys, the phases formed are determined primarily by their heat of formation, those with the maximum thermal effect being the most readily formed. This is not the case when high-melting-point alloys are acted upon by molten pure metals. In such cases an excess of one of the metals in the alloy and the rate of solution of the phases formed are the controlling factors.

Rhenium-Iron Alloys. (Metallurgist, 1939, vol. 12, Apr., pp. 22–24). A summary in English is presented of the work of H. Eggers on the binary iron-rhenium system. A full account of this work appeared in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1938, vol. 20, No. 12, pp. 147–152. (*See* Journ. I. and S.I., 1938, No. II., p. 328 A).

CORROSION OF IRON AND STEEL

(Continued from pp. 46 A–48 A)

The Study of Corrosion in Belgium. N. Goldowski. (Métaux et Corrosion, 1939, vol. 14, Mar., pp. 33–37). The authoress gives some information on the study of corrosion which is now being undertaken in Belgium. The Belgian Corrosion Commission was formed in June 1936 with Professor Erculisse as president and its members are drawn from four main sources, viz.: universities and high schools, state and private laboratories, consumers and producers. The main purpose of the Commission is to study the protection of steel by paint. Fourteen testing stations have been established, three of which are in the Belgian Congo, the others being situated in different parts of Belgium, where the test specimens are exposed under different atmospheric conditions. The specimens are all of the same quality steel, and a series of long-time exposure tests is now being undertaken to ascertain the value of many different kinds of paint.

On the Intercrystalline Corrosion of Steel by Nitrates. M. Smialowski. (Métaux et Corrosion, 1939, vol. 14, Apr., pp. 56–60). The author describes some experiments made with the object of determining the effect of the amount of carbon present in steel upon the intercrystalline corrosion when subjected to attack by a solution of ammonium nitrate. Three kinds of steel wire were tested; these contained: (*a*) carbon 0·005%, chromium 0·08%, nickel 0·03%, copper 0·05% and aluminium 0·01%; (*b*) carbon 0·07% and copper 0·20%; and (*c*) carbon 0·82%, chromium 0·11%, nickel trace, and copper 0·02%. He arrived at the following conclusions: (1) Steels (*a*) and (*b*) corroded at about the same rate in an 8*N*.solution of ammonium nitrate; (2) specimens of wire 1 mm. in dia. of steels (*a*) and (*b*) broke in less than 8 hr. under a load of about one-quarter of their tensile strength, whilst the pearlitic steel (*c*) required a load exceeding two-thirds of its tensile strength to break it; these tests were made in the vapour from boiling ammonium nitrate solution; (3) ammonium nitrate solution corrodes steel more rapidly than sodium nitrate solution and the rate of corrosion by calcium nitrate solution is still less; and (4) the mechanical properties of 1 mm. thick sheet steel containing 0·05% or 0·14% of carbon are only slightly affected after five days in a boiling solution of 8*N*.ammonium nitrate.

Contact Corrosion of Stainless Steel. J. Arnott. (Metallurgia, 1939, vol. 19, Apr., pp. 223–224). The author describes his investigation of the local attack on some types of stainless steel which occurs when they are in contact with apparently innocuous non-

metallic substances while immersed in, or wetted by a liquid, such as sea-water, which, in absence of such contact, has no action on the steel. The author calls this "contact corrosion," and the particular instance he examined was the pitting of stainless steel rods in reciprocating units operating in cold sea-water. The steel contained 1·82% of nickel and 16·10% of chromium. He tested some specimens of stainless steel rods by wrapping them in different kinds of packings and partially immersing them in water. Definite pitting was produced in all cases within ten days. The extent of the attack varied, being least under carbon packing, and greatest under leather. Further tests showed that the corrosion was about the same whether the steel was hardened or not. The investigation showed that even the austenitic stainless steels were subject to this form of attack, but that it is much less likely to occur if the steel contains molybdenum.

New Stainless Steel Resistant to Sulphuric Acid. Yu. Nekhendzi. (Stal, 1938, No. 8–9, pp. 60–68). (In Russian). Work by previous investigators showed that the development of a steel resistant to sulphuric acid should be directed towards obtaining an austenitic steel with a high nickel content with additions of molybdenum and copper. The chromium-nickel steels investigated with varying carbon, silicon, manganese, chromium, nickel, molybdenum and copper contents fall into three groups: (1) Steels of the 18/8 type with and without additions of molybdenum and copper which were used mainly for comparison purposes in the corrosion tests; (2) the new 8/18 type of stainless steels with and without additions of molybdenum and copper, and (3) the 25/5 type of steel. Tests on all three groups included a study of their casting properties, determination of mechanical properties in the as-cast and hot-forged conditions and an investigation of the heat-treatment temperatures and their effect on the corrosion resistance. The loss in weight was determined in sulphuric, hydrochloric, phosphoric and acetic acids, as well as in solutions of various inorganic salts at different temperatures and in sea-water. A sufficiently high corrosion resistance for practical purposes for use in contact with sulphuric acid (up to 65%) is obtained only with the new 8/18 steel with 3·5% of molybdenum and 4% of copper. This steel resists the action of boiling sulphuric acid (up to 50%) and cold hydrochloric acid (up to 30%). The ordinary 18/8 steel does not resist boiling sulphuric acid; its corrosion resistance is lowered by raising the carbon content but improved by additions of molybdenum above 2·5% and preferably up to 4%. The 25/5 steel has satisfactory corrosion resistance and mechanical properties and can be used in contact with strong phosphoric acid at elevated temperatures.

Some Conclusions from an Experimental Study of the Corrosion of Welds. A. Portevin and A. Leroy. (Métaux et Corrosion, 1939, vol. 14, Apr., pp. 49–56). The authors review some of the experimental work undertaken by the Institut de Soudure Autogène on

the corrosion of welds. They consider the susceptibility to corrosion of the parent metal, the weld metal, and finally that of the two metals welded together. They point out that the welding heat affects the grain size but not the chemical composition, and that the areas where the larger grains predominate are most readily attacked by acid. They also show that mill-scale adhering to mild steel some distance from a weld actively promotes corrosion. They are of the opinion that, generally speaking, the presence of a welded joint is not a factor tending to promote or increase the rate of corrosion.

Pitting Corrosion of Cast-Iron and Steel Pipes. L. Olsansky. (Institute of British Foundrymen (International Foundry Congress), June, 1939, Preprint No. 685). In order to determine the influence of the cast skin in the case of cast-iron pipes, and the influence of mill scale in the case of rolled steel tubes, on the resistance to corrosion, the author, who is a technical investigator at the municipal gasworks at Brno, made some tests on sections of rolled tubes and cast pipes with a 5% solution of nitric acid. These tests confirmed the importance of the as-cast skin on cast-iron pipes and of the mill scale on steel tubes for the resistance of such tubes and pipes to corrosion. Further tests proved that it is not possible to evaluate the resistance to corrosion of cast-iron pipes or steel tubes in the case of machined material.

Welding Overlays on Turbine Blades to Prevent Cavitation. L. M. Davis and J. M. Mousson. (Metal Progress, 1939, vol. 35, Apr., pp. 349–354). The authors describe the measures taken to prevent cavitation corrosion on the cast carbon-steel turbine blades for the Safe Harbor Water Power Corporation. The castings weighed about 5½ tons each, and it was decided to weld on two layers of a corrosion-resisting alloy. Before doing so a large number of specimens of similar steel were coated with nickel-chromium steels of different analyses and subjected to accelerated corrosion and machinability tests. The results showed that low-alloy steels were just as subject to cavitation corrosion as plain carbon steel, whilst with the higher alloy deposits the loss was much less; it was also observed that the harder the metal the smaller was the loss in weight by corrosion. It was eventually decided to use electrodes of 18/8 stainless steel. The authors present the results of the tests in tables and also give some cost data which enable the prices of carbon steel blades before and after coating to be compared with those of blades made of solid chromium and solid nickel-chromium steel.

ANALYSIS

Perchloric Acid. C. M. Johnson. (Iron Age, 1938, vol. 142, Oct. 13, pp. 255–260; Dec. 29, pp. 16–19, 22; 1939, vol. 143, Feb. 16, pp. 33–35). In this series of articles the author describes how the Crucible Steel Co. of America developed a new technique for the determinations of manganese, sulphur, nitrogen, molybdenum, tungsten and metallic iron in corrosion-resisting steels, iron-alloys and iron ores, as well as a method for the determinations of sulphur and nitrogen in coal and coke. All the methods are based on the use of perchloric acid. The first and second parts deal with determination of manganese in alloy steels, and in the third the author shows how to determine the sulphur in steel, coal and coke.

A New Method for the Determination of Aluminium in Ferrous Alloys. E. C. Pigott. (Journal of the Society of Chemical Industry, 1939, vol. 58, Apr., pp. 139–142). The failure of recognised methods for the determination of aluminium to yield reproducible results when applied to complex ferrous alloys led to a close investigation of 8-hydroxyquinoline as a precipitant. Apparently the advantages of this reagent were outweighed by separation difficulties. These were overcome by applying a greatly simplified process for converting the interfering elements into non-interfering complex cyanides. Slight modifications rendered this rapid cyanide-hydroxyquinoline process directly applicable to the most complex materials. A description of the method is preceded by theoretical considerations, and for certain materials more concise procedures are given. When applied to solutions representing practically all the elements to be found in irons and steels, the method yielded very satisfactory results. The values obtained are tabulated.

Micro-Method for Determining Carbon in Steel. M. H. Kalina and T. L. Joseph. (Heat Treating and Forging, 1939, vol. 25, Apr., pp. 169–173, 177; Blast Furnace and Steel Plant, 1939, vol. 27, Apr., pp. 347–351). After considering the limitations of a number of methods of determining the carbon in steel, in particular that by which the carbon is converted to carbon dioxide and absorbed by Ascarite, the authors describe in detail the apparatus used for an improved volumetric method based upon the absorption of carbon dioxide by a standard solution of barium hydroxide $Ba(OH)_2$. This apparatus includes a constant volume pipette for adding small quantities of the standard barium hydroxide solution to the absorbing tower and a capillary pipette from which small but measurable amounts of hydrochloric acid can be released for titrating the excess of the absorbent. The whole operation takes about 20 min. and with proper precautions the carbon dioxide detector is sensitive to 0·0015 mg. of carbon.

Analysis for Residual Chromium in Steel. A. E. Pavlish and J. D. Sullivan. (Iron Age, 1939, vol. 143, Apr. 27, pp. 38–39). After pointing out some of the disadvantages of the colorimetric method of determining residual chromium in steel in the final stage of which the yellow chromate is compared with a sample of known chromium content, the authors describe a rapid and more accurate method which has been developed at the Battelle Memorial Institute. The indicator used for the titration in the new method is ortho-phenanthroline.

On Hydrogen, Its Determination and Its Behaviour in Steels of Different Compositions. Y. C. Chiu and F. Willems. (Archiv für das Eisenhüttenwesen, 1939, vol. 12, Apr., pp. 485–498). In the first part the authors describe the conditions under which it is possible to determine the hydrogen in steel. They describe the refinements added to a hot-extraction apparatus which incorporated a chamber heated by a carbon spiral. This was used to determine the total oxygen, and which led to the construction of a new apparatus. In the second part they describe hydrogen determinations made with the new apparatus with particular reference to work on specially prepared hydrogen-enriched steels.

Non-Metallic Inclusions in Copper- and Chromium-Copper Steels. N. Leve, A. Gurevich and I. Malashenko. (Stal, 1938, No. 8–9, pp. 51–60). (In Russian). Using a number of copper (0·18–0·78% of copper) and chromium-copper (0·41–0·70% of chromium, 0·40–0·64% of copper) steels, the authors applied the chlorination and the mercuric chloride methods for the determination of non-metallic inclusions. The chief disadvantage of these methods is the partial decomposition of the unstable inclusions during the separation of the slag residue from the carbides. A combined anodic mercuric-chloride method of determining non-metallic inclusions was developed which involved treatment of the residue obtained electrolytically by Fitterer's method with a solution of mercuric-chloride in the presence of citric acid (separation of non-metallic inclusions from carbides). By this treatment inclusions such as sulphides, manganese and copper oxides are recovered unchanged. As compared with the direct mercuric-chloride method, the new process is not restricted to steels low in sulphur and phosphorus and also requires less mercuric chloride. The article contains the results of some preliminary tests on the applicability of the chlorination method, the action of chlorine on copper and copper oxides, and the results of the chemical analysis of the non-metallic inclusions separated from the copper and chromium-copper steels by the new anodic mercuric-chloride method.

Quantitative Estimation of Non-Metallic Inclusions in Steel. R. Hunter. (Metal Treatment, 1938–39, vol. 4, Winter Issue, pp. 177–181). After reviewing the methods by which the number of non-metallic inclusions in steel can be assessed by means of the microscope, the author describes a method developed in the

laboratory of the Clyde Alloy Steel Co., Ltd. In this method the inclusions are counted and their length measured, and the statement of results gives the length of inclusions per square inch of steel, the average length of the inclusions, and the length and approximate thickness of the largest inclusion.

Determination of Lead in Carbon and Alloy Steels. G. E. F. Lundell. (Metal Progress, 1939, vol. 35, Apr., p. 383). The author describes a method employed by the National Bureau of Standards for determining the lead in the new lead-bearing steels which are now on the market. Stated briefly, the method consists of dissolving the sample in hydrochloric acid, heating the solution and converting the lead to lead sulphide with sulphuretted hydrogen, the sulphide precipitate is then dissolved in nitric acid and lead peroxide is obtained from this solution by electrolysis. The amount of lead can be calculated from the weight of the peroxide deposited.

Determination of Lead in Carbon and Alloy Steels. C. M. Johnson. (Metal Progress, 1939, vol. 35, Apr., pp. 383–384). The author describes two methods of determining lead in lead-bearing steels, one is a useful qualitative test which will detect the presence of lead when 0·04% or more is present, and the other is a quantitative method of determining the lead as sulphate.

Control of Lead in the Steel Plant. E. D. Martin. (Metal Progress, 1939, vol. 35, May, pp. 457–463, 518). The increased production of the new lead-bearing steels, such as "Ledloy," have caused manufacturers to study the risks to which the men employed in making the alloy may be exposed and the methods by which these risks may be kept within safe limits. In this paper the author discusses these questions on the basis of experience gained at the Inland Steel Company's works where "Ledloy" is made. It has been found that man can normally absorb from food or from the atmosphere a certain amount of lead and eliminate it without harm, and American investigators have established a "threshold value" of lead in the atmosphere below which the air is safe to breathe and above which there is presumed to be a risk to health. It is assumed that a workman breathes about 10 cu. m. of air per day, and the "threshold value" is therefore specified in milligrammes per 10 cu. m. The United States Public Health Service has established this value at 3. The author also describes in detail the apparatus used and the procedure for determining the amount of lead in the atmosphere at various parts of the steel plant and the results obtained.

The Determination of Manganese in Steel with Special Reference to Highly Alloyed Corrosion- and Heat-Resisting Steels. B. Bagshawe. (Journal of the Society of Chemical Industry, 1939, vol. 58, Mar., pp. 106–108). For the determination of manganese in chromium and other alloy steels, the method which has been used for many years is based on conversion into permanganic acid

with sodium bismuthate following a zinc oxide separation of the iron-chromium group from neutralised sulphate solutions. For some time it has been apparent that this method falls short of requirements in that it is not sufficiently flexible and convenient for use on the more complicated and varied alloy combinations found in modern steels.

Experiments with a modified form of zinc oxide separation from perchloric acid solutions have shown that under properly controlled conditions a perfect separation of iron and chromium from manganese can be obtained. The use of perchloric acid opens up the possibility of rapid dissolution of almost any type of steel by means of mixed hydrochloric and nitric acids followed by perchloric acid "fuming" which ensures complete decomposition of complex acid-resisting carbides. The great advantage of this treatment is that almost any type of steel can be handled in a minimum of time by a standardised solution treatment which does not require modification to meet individual cases. A persulphate finish is recommended, operating in sulpho-phosphoric solution which ensures permanganate stability and thus permits complete destruction of excess of persulphate and subsequent titration with ferrous sulphate and permanganate. There is no danger of interference from chromium, since under specified conditions the removal of this element at the zinc oxide stage is almost quantitative. The method is applicable to cobalt steels.

Determination of Silicates and Silicides in Steel. N. V. Udovenko. (Zavodskaya Laboratoriya, 1939, No. 1, p. 95). (In Russian). It has been found that the proportion of silicide to silicate in one and the same type of steel varies depending on production conditions. The silicate portion is determined by dissolving the steel in hydrochloric acid, adding potassium chlorate, boiling and filtering the cooled solution. The solution is evaporated to dryness, the residue ignited, treated with hydrochloric acid and hot water, and the solution filtered. The residue corresponds to the silicide portion of the silicon content of the steel. Results should be checked by determining the total silicon content by the usual method.

Rapid Method of Determining Titanium in Ferro-Titanium. P. I. Shporenko. (Zavodskaya Laboratoriya, 1939, No. 1, p. 96). (In Russian). To determine the titanium in ferro-titanium the sample is dissolved in a mixture of hydrochloric and sulphuric acids and the solution evaporated until white fumes come off. After diluting with water the silica is filtered off and the solution is subjected to electrolysis using a mercury cathode until the iron is completely removed. The titanium is precipitated as metatitanic acid from the residual solution by hydrolysis or with Cupferron from citric acid solution. The time required is 4–4½ hr.

The Application of the Polarograph in the Steelworks Laboratory. II. Experiments to Determine Vanadium, Chromium and Molybdenum

after Separation of the Iron with Alkali Hydroxides. G. Thanheiser and J. Willems. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 4, pp. 65–78). The principle of the polarographic method of analysis and its application for the determination of copper, nickel and cobalt in steel have already been described. (*See* Journ. I. and S.I., 1937, No. II., p. 108 A). The authors undertook the present investigation with the object of separating vanadium, chromium and molybdenum from iron and to ascertain with what degree of accuracy these elements could be determined in the filtrate by the polarograph. The authors describe the investigation in detail and present the results in tables and by graphs. They discovered a number of reasons why the vanadium could not be determined. They were successful in determining the chromium, and they explain the effect of changes in temperature, of the rate at which the drops fall from the capillary tube of the apparatus, and of the ion concentration upon the results, and describe an electrical compensating device which eliminated the necessity of photographing the amperage-voltage curve and thus reduced the time required for the determination. Molybdenum cannot be separated by alkaline solutions, but the authors developed a polarimetric method of determining this element; this was based on titrating the molybdate with lead perchlorate, the end point being indicated by the occurrence of a diffusion current. They show that the polarimetric method has certain advantages over the polarographic method for certain elements.

Recent Developments of Spectrographic Analysis. E. van Someren. (Metallurgist, 1939, vol. 12, Apr., pp. 29–31). The author summarises information on the stage of development now reached in the application of the spectroscope for making metallurgical analyses by quoting from the discussion which took place following a paper on spectrography in the non-ferrous metallurgical industry by F. Twyman. (*See* Engineer, 1939, vol. 167, Mar. 24, pp. 387–388).

Determination of Nitrogen in Electric-Furnace Melting Slags. M. S. Kovtuk. (Zavodskaya Laboratoriya, 1939, No. 1, pp. 93–95). (In Russian). A number of samples of electric-furnace slags were analysed for nitrogen by (*a*) dissolving in hydrochloric acid, (*b*) dissolving in hydrochloric acid with subsequent treatment of the insoluble residue with fluosilicic acid and (*c*) dissolving in hydrochloric acid followed by fusion of the insoluble residue with potassium bisulphate (Klinger's method). In all three cases the ammonia was subsequently determined by distillation. Methods (*a*) and (*c*) tended to give low results and (*b*) is regarded as the most satisfactory.

A Decade of Sampling. E. S. Grumell. (American Institute of Mining and Metallurgical Engineers, 1939, Technical Publication No. 1044). The author reviews the extensive research work which has been done during the last ten years on the sampling of coal

and coke, pointing out where substantial progress has been made and drawing attention to points requiring further investigation.

The Development of the Methods of Analysing and Testing Coal. P. Erculisse. (Revue Universelle des Mines, Mémoires, 1939, vol. 15, Jan., pp. 3–15). After reviewing the present state of knowledge of the properties of coal and the present methods of analysis and testing, the author refers to the new purposes for which coal is used and the necessity for further study of its physical properties. He describes a rapid method for the determination of the fusain and durain and discusses the carbon reactions at different temperatures.

The Determination of Pyritic Sulphur in Bituminous Coal. W. Mantel and W. Radmacher. (Fuel in Science and Practice, 1939, vol. 18, Mar., pp. 80–84). An English translation of an article which appeared in Glückauf, 1937, vol. 73, Oct. 30, pp. 989–993. (*See* Journ. I. and S.I., 1938, No. I., p. 226 A).

The Determination of Sulphur in Solid Fuels and Iron Pyrites by Combustion in a Stream of Oxygen. A. Seuthe. (Glückauf, 1939, vol. 75, May 13, pp. 409–411). The author describes in detail a rapid method of sulphur determination which experience has shown to be very useful and accurate for use with coke, coal, brown coal, iron pyrites, ash, slags and sulphide ores. (*See* Journ. I. and S.I., 1938, No. I., p. 363 A).

A Note on the Determination of Sulphur in Coal. N. Simpkin and E. H. Jones. (Journal of the Institute of Fuel, 1939, vol. 12, Feb., pp. 168–170). The authors describe two modifications of the Eschka method for the determination of sulphur in coal. The Eschka method is that described in British Standard No. 687–1936, but in that publication some doubt is cast on its reliability when the sulphur content exceeds 2%. The modifications described in the present paper are called the Research Association method and the baking method and with them accurate determinations can be made when the sulphur content is very high.

BOOK NOTICES

(Continued from pp. 49 A–56 A)

Betriebstechnische Sammelmappe. Die gesammelten und überarbeiteten Blätter des Betriebsarchivs aus den letzten Jahrgängen der Zeitschrift "Maschinenbau/derBetrieb." 1 Ergänzungslieferung. Berlin: VDI-Verlag. G.m.b.H. (Price 2.40 RM.)

In the Journal of the Iron and Steel Institute 1937, No. I. a review appeared of the first publication in this series. The work is composed of a collection of pages, one from each issue of Maschinenbau/derBetrieb, dealing with various aspects of workshop practice. The present supplementary set consists of 23 leaves and an index. The subjects covered are of great variety and are grouped into sections for indexing purposes. Where, as often is the case, one item does not fit conveniently into any particular section it is indexed under all the headings that may reasonably be considered to include such information. Under the first heading, "General works problems; lay-out, supervision, testing" appear such varied items as accident prevention, fire precautions, and measurement of screw threads. Other general headings include works equipment, tools, machine tools, heat treatment, and surface treatment, and among these are to be found sections on defects in steel, hardness testing, lubrication of machine tools, lubricant economy, and cut and milled files. As is indicated by the above selection from the contents it would be difficult to define the present scope of the publication. It must suffice to say that the information provided is of the type to delight the intelligent foreman or workshop superintendent, but as a work of reference there are many gaps to be filled up in future issues. The leaves are printed on one side only and therefore could be mounted on cards for general use, the printing and arrangement are clear and attractive and excellent graphs and line diagrams are provided where necessary.

STEPHEN L. ROBERTON.

SCHRADER, ANGELICA. "*Ätzheft.*" Anweisung zur Herstellung von Metallschliffen. Verzeichnis von Ätzmitteln. Verfahren zur Gefügeentwicklung. Auf Grund praktischer Erfahrungen ausgewählt und zusammengestellt. Zweite verbesserte und erweiterte Auflage. 8vo, pp. 24. Berlin, 1939: Verlag von Gebrüder Borntraeger. (Price 1.60 RM.)

The sub-titles of this little book are "Methods for the production of metal microsections, a table of etching reagents, processes for developing microstructure." All this information is contained in concise tabular form in the twenty-one pages of text. Other publications on the same subject have taken much more space to convey practically the same information in a less satisfactory form. Here we have no bare collection of recipes collated from various sources and set down to confuse the enquirer with too wide a selection of reagents and processes. Frl. Schrader has certainly made a study of

international literature for her material, but the information given is based on the results obtained in her metallographic studies in the Institut für Metallkunde der Technischen Hochschule, Berlin. Frl. Schrader's eminence as a metallographist is appreciated in this country no less than in her own, if for nothing else than her magnificent work in collaboration with Prof. Hanemann in the preparation of the "Atlas Metallographicus." The technique employed at the Institut should thus be of interest to all students of metallography, and here in this little inexpensive volume is to be found that information. The methods described cover all the principal industrial alloys; polishing methods, etching solutions, and reagents for the identification of specific constituents being given where necessary. In the steel section sulphur printing and the detection of strain by etching are dealt with, but no mention is made of polishing methods or etching reagents for the identification of non-metallic inclusions, a subject that may very reasonably be excluded from the scope of the book. A table is given for the identification of the carbides, phosphides and nitrides in steels, and the system of Keller and Wilcox for the differentiation of the constituents in aluminium alloys is reproduced. The conciseness of the information and the tabular arrangements of the major portion of the book make translation relatively simple, and metallographists in this country should not be deterred by linguistic difficulties from investing in so useful a handbook compiled by an authoress whose experience in the subject makes her a recognised authority.

STEPHEN L. ROBERTON.

VEREIN DEUTSCHER INGENIEURE. "*VDI Jahrbuch 1939. Die Chronik der Technik.*" Herausgegeben im Auftrage des Vereines deutscher Ingenieure von A. Leitner. 8vo, pp. 298. Berlin, 1939: VDI-Verlag. G.m.b.H. (Price 3.50 RM.)

This edition of the VDI Yearbook follows the same system as its predecessors. The entire field of engineering activity is divided into broad sections, and these are further subdivided more particularly into a number of sub-sections each written by an authority on the matter dealt with. Each author contributes a review of the inventions, improvements and progress reported during the previous year, with references to the literature where fuller details may be studied. New books that have appeared in the last year, chiefly in Germany, are also noted. The foreword, written by Dr. H. Kölzow, director of the VDI, records the creation of Greater Germany by the incorporation of Austria and the Sudetenland in the Reich, and states that the new tasks that confront engineers as a result of these territorial acquisitions are immeasurably great. That the new provinces of the Reich are already contributing their quota to the domestic supply of raw materials is evident in the mention of successful new oil wells sunk in the proved oil field of Zistersdorf, near Vienna. In many of the articles the mention of synthetic products, or the use of alternatives to the use of imported raw materials, shows how intensely the drive towards self-sufficiency in Germany is being carried out. Even the condensed record of such activities makes impressive reading. As in previous years the volume gives an excellent cross-section of engineering progress both in Germany and elsewhere, and to the engineer desirous of keeping in touch with the latest developments in any branch of technology the book will describe the trends of modern progress and indicate the sources from which fuller details may be obtained.

STEPHEN L. ROBERTON.

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REFRACTORY MATERIALS

(Continued from pp. 60 A–62 A)

Softening and Fusion of Refractories. A. Kufferath and E. R. Thews. (Canadian Metals and Metallurgical Industries, 1939, vol. 2, Apr., pp. 82–85). The authors point out that the softening points of refractories for metallurgical furnaces depend upon the following factors: (1) The softening points of their main constituents and their impurities; (2) the binding materials used in the manufacture of the bricks; (3) the methods of manufacture; (4) the degree and uniformity of loading of the bricks in the hot furnaces; (5) the foreign substances, such as slags, introduced into the bricks during the operation of the furnaces; and (6) the porosity of the bricks. They discuss some practical examples which illustrate these points and suggest means of dealing with some of the difficulties encountered.

Refractories and Thermal Shock. J. F. Hyslop. (Transactions of the British Ceramic Society, 1939, vol. 38, May, pp. 304–309). The author investigated the differences between fractures in refractory bricks caused by sudden cooling and by rapid heating, and describes tests made with two rather abnormal firebricks with more or less extreme properties. The results showed that it is quite possible to have refractories which behave differently on the application of thermal shock. The two bricks were given similar thermal shocks. In one case the nature of the fractures was tangential or shearing, the brick losing corners, ends and edges, whilst in the other case the type of fracture was tensile. The nature of the resistance of a refractory to thermal shock is thus seen to depend upon its tensile and shear characteristics. This conclusion is important, as it explains a number of anomalies between laboratory testing and service behaviour, and it also shows the extent of the field which has to be covered in the correlation of thermal shock tests, properties of refractories, and practical service.

Specifications and Tests from the Refractories Maker's Point of View. G. V. Evers. (Journal of the Society of Glass Technology, 1939, vol. 23, Apr., pp. 118–127). The author discusses specifications respecting refractoriness, porosity, spalling, permeability, after-contraction and after-expansion, the presence of black cores and the texture of refractory bricks, and notes some of the difficulties experienced by a manufacturer in applying them. He considers that it is wiser for the user not to insist upon any specification unless it is one which experience has shown to cover the essential points of the user's particular requirements and discards all reference to non-essentials. He also thinks it desirable that

some competent authority should draw up a series of tests of different grades of severity designated A, B, C, &c. These graded tests should not be combined in one standard specification, but should be issued in such form as to permit of their individual selection by the user and maker acting in co-operation and according to the essential requirements to be fulfilled by the refractory material in question.

Some Properties of Semisilica Brick. G. B. Remmey. (Journal of the American Ceramic Society, 1939, vol. 22, June, pp. 193–199). The author describes some methods of testing refractory bricks and their application to three grades of " semi-silica " bricks made from New Jersey clays. One of these had a very high refractoriness-under-load and contained 82% of silica, the second had a high spalling resistance and contained 75% of silica and the third was a very hard brick with a high resistance to abrasion and to the action of slags.

Recent Developments in Basic Refractories. J. H. Chesters. (Journal of the West of Scotland Iron and Steel Institute, 1939, vol. 46, Jan., pp. 65–70). The author reviews recent developments in the field of chrome-magnesite, magnesite and dolomite bricks. He shows that good chrome-magnesite bricks with a high resistance to thermal shock and to spalling can be produced by proper control of the grain size of the mix, of the chrome/magnesite ratio and of additions. He gives the properties of eight brands of chrome-magnesite and eleven magnesite bricks. With regard to the manufacture of magnesite bricks, the author refers to a new material which has just become available, *viz.*, magnesia extracted from sea-water and dolomite. The clinker prepared by calcining the washed magnesium hydrate has certain peculiar properties, notably the ease with which it can be used in the production of magnesite bricks of high thermal-shock resistance. Some of the first of these bricks made withstood thirty temperature reversals without cracking and showed a very high refractoriness-under-load. Bricks made from this magnesia are now in use in the front wall of an open-hearth furnace, but it is too early to give an opinion on their probable life.

A New Method of Assessing the Stability of Refractory Structures. D. Petit. (Transactions of the British Ceramic Society, 1939, vol. 38, May, pp. 313–327). The author develops a method of calculating the safe working load and the safe working temperature of refractory brick structures. This is an English translation of an article which appeared in Chaleur et Industrie, 1939, vol. 20, Feb., pp. 239–248; Mar., pp. 273–288. (*See* p. 61 A).

Refractories for Heat-Treatment Furnaces. (Metallurgia, 1939, vol. 20, May, pp. 35–36, 38). The properties of some of the improved refractory bricks and cements now on the market with special reference to sillimanite and diatomaceous insulating bricks are briefly reviewed.

Basic Linings for High-Frequency Induction Furnaces. (British Steelmaker, 1939, vol. 5, May, p. 180). A brief description is given of a method of preparing basic refractory linings for high-frequency induction furnaces by means of tongued and grooved spinel sections. The use of magnesite combinations with alumina as the basis of the spinel composition considerably reduces the amount of permanent contraction. After the sections have been put in place the space behind them is rammed with a refractory composition which effectively seals the joints. Experience has shown that these linings last much longer than those made of rammed magnesite compositions only.

The Problem of Lining High-Frequency Furnaces. B. Stålhane and V. Anderson. (Jernkontorets Technical Meeting, June, 1939). Introducing their paper with a brief historical review of the development of the high-frequency electric steel furnace, the authors proceed to a consideration of the difficulties which have been encountered with different linings and explain the reasons for the different results obtained with quartz and magnesite linings. They deal next with the possibilities of developing linings of basic materials and in this connection they present curves showing the expansion properties of "Zirkit" (a material containing 80–90% of zirconium oxide), magnesite, spinel, alumina, sillimanite and zirconia. In the concluding part of the paper the authors specify the requirements of a good basic lining in terms agreed upon by themselves in conjunction with L. Dreyfus, L. Högel and the Swedish General Electric Company. As a result of subsequent research a suitable material called "BM mixture" (in Swedish "*BM-massa*") has been produced. This consists mainly of magnesite to which are added certain new synthetic products of "Zirkit." This material can be rammed to a density equivalent to 20% porosity and its contraction on sintering, even after long periods at high temperature, is less than 1%. Its melting point is above 1900° C. Tests of this material in a 32-cwt. electric furnace at Sandviken have given good results and the lining shows no tendency to cracking after seventy charges.

FUEL

(Continued from pp. 63 A–65 A)

Steel Plant Fuel Accounting. H. V. Flagg. (Iron and Steel Engineer, 1939, vol. 16, Apr., pp. 21–27). After showing the importance of an accurate system of fuel accounting to the management of a steelworks, the author describes the system employed at the plant of the American Rolling Mill Co., and includes a description of the metering system and the reports and standards adopted at these works.

A New Process for the Cleaning of Coal by Heavy Liquids. M. G. Driessen. (Revue Universelle des Mines, 1939, vol. 82, May, pp. 177–193). After reviewing the characteristics of processes of washing coal using media of high specific gravity, the author gives a full description of the process developed by the Dutch State Mines in which a loess suspension (sp. gr. 1·45) is used. A brief account of this process appeared in Génie Civil, 1939, vol. 114, June 10, pp. 484–487 and in some English journals. (*See* p. 63 A).

Barvoys Gravity Process of Coal Washing. W. A. Machin. (Iron and Coal Trades Review, 1939, vol. 138, June 9, pp. 998–1000). The author describes the theory and practice of the Barvoys process of coal washing in which the separating medium used is a suspension of finely-ground barytes and clay in water. This process was also described in detail in Colliery Engineering, 1939, vol. 5, May, pp. 169–175. (*See* p. 64 A).

Carbonizing Properties and Petrographic Composition of Pittsburgh-Bed Coal from Bureau of Mines Experimental Mine, Bruceton, Allegheny County, Pa. A. C. Fieldner, J. D. Davis, R. E. Brewer, W. A. Selvig, D. A. Reynolds and G. C. Sprunk. (United States Bureau of Mines, 1939, Technical Paper 594).

Dangerous Swelling Pressures in Carbonisation Practice. G. E. Foxwell. (Journal of the Institute of Fuel, 1939, vol. 12, June, pp. 281–290). The importance in coke-oven practice of the swelling pressure set up by certain coals is discussed. In order to avoid local concentrations of swelling coal in the oven charges, such coal has to be blended with a less dangerous one. The swelling pressure of coal increases with increased bulk density and can, therefore, be reduced by loosening the coal charge. This can be effected by grinding to a finer state and by suitable adjustment of the moisture content. The standard methods in general use on the Continent for the determination of the pressure-generating propensities of coal are described at some length, with particular reference to the various types of Koppers' and of Nedelmann's apparatus.

Plasticity and the Swelling of Coal. C. A. Seyler. (Journal of the Institute of Fuel, 1939, vol. 12, June, pp. 301–303). The author criticises methods of determining the swelling properties of coal which are based upon the amount of sand which could be agglomerated by one part of coal into a coke capable of resisting crushing by a given weight. In the opinion of the author, this method and modifications of it are based on the fundamentally erroneous conception that coke is a sort of briquette formed by the cementation of an infusible part of the coal by a fusible component extruded from the particles and acting as a binder. His view is that coke is a vesicular mass produced by gas bubbles in a uniform substance which has passed through a viscous or plastic state. He defines a number of terms used with regard to the plasticity of coke and states briefly the lines upon which investigations are now being conducted by himself and H. Edwards with the aid of the Fuel Research Board.

PRODUCTION OF IRON

(Continued from p. 66 A)

Modern Methods of Smelting Iron Ores. R. Durrer. (Angewandte Chemie, 1939, vol. 52, May 27, pp. 377–383). The author reviews modern smelting practice with particular reference to the smelting of low-grade ores, and to some direct processes for the production of steel.

The Decomposition of Crude Phosphates by Smelting with Soda Slag. K. H. Hennenberger. (Stahl und Eisen, 1939, vol. 59, June 1, pp. 662–663). The author describes a process for the utilisation of the slags which are now available in Germany as a result of the use of soda ash for the desulphurisation of pig iron. This process is being exploited by the Röchling'sche Eisen- und Stahlwerke, G.m.b.H., in conjunction with two other companies. The process consists essentially of mixing the slag with crude phosphate, and heating the mixture in a rotary kiln to decompose the phosphate in order to produce a soluble fertiliser. Operations on an experimental scale have been successful and a full-scale plant has been designed.

The Influence of the Chemical Composition on the Temperature-Viscosity Ratio of Acid Blast-Furnace Slags. K. Endell and R. Kley. (Stahl und Eisen, 1939, vol. 59, June 8, pp. 677–685). In Germany the change-over from the basic to the acid blast-furnace process has brought to the fore, among other problems, the properties of the slag produced, and the authors here describe a suspended-ball apparatus for testing the viscosity of molten slags and discuss the results obtained with it. Seven acid slags with lime/silica ratios between 0·39 and 0·86 were tested at 1400° C. and were found to have viscosities between 83 and 11 poise. With a viscosity of 75 poise at 1400° C. it was found that the slag flowed easily from the furnace, but the viscosity should not be higher than this. Using the ratio :

$$(CaO + MgO + FeO + MnO + Alkalis)/(SiO_2 + Al_2O_3)$$

calculated in weight per cent. as a viscosity coefficient, the authors found that when this coefficient is higher than 0·6 the viscosity of the acid slag at 1400° C. will be less than 50 poise. If it were found uneconomic to keep the oxide additions up to the required ratio, the authors point out that bringing the tapping temperature up to 1500° C. would effectively lower the viscosity of the slag, but to attain such a temperature would require the addition of oxygen to the blast.

New Methods of Using Blast-Furnace Slags. E. Belani. (Montanistische Rundschau, 1939, vol. 31, May 16, pp. 303–305). The

author describes some new uses for blast-furnace slag in the refining of oils, fats and waxes. The slag is pulverised by being projected at high velocity in a stream of cold water against a plate; the product is then dried and screened and passed over a magnetic separator to remove any particles of iron. The size of grain used is 0·01–0·8 mm. The calcium silicates in the slag are highly absorbent and remove acid resins and other substances present in colloidal form which affect the taste and smell of the materials being refined. He also discusses the preparation of pulverised slag for use as a substitute for fuller's earth and points out some advantages of the former; these include its low cost and the fact that its quality improves after being stored for a long time.

Refined-Iron Works of the A. M. Byers Company, Pittsburgh. (Iron and Coal Trades Review, 1939, vol. 138, May 26, pp. 924–926). A description is given of the plant and process employed for making refined iron at the works of A. M. Byers Company, Pittsburgh. For this process both liquid iron and liquid slag are required. The former is furnished from a Bessemer converter, the latter from a tilting slag furnace of open-hearth design. The process is then completed by slowly pouring the molten iron into a bath of slag which is kept at a temperature slightly below that of the iron. After the desired weight of iron has fallen into the slag, the excess slag is decanted and there remains a ball of pure iron in the bottom of the vessel which contained the slag. The ball thus obtained is subjected to several pressing operations and shaped into a bloom about 17 in. by 21 in. in section. The mills at these works include a 46-in. universal mill, a bar mill and a skelp mill.

Pure Iron Powder. A. H. Allen. (Steel, 1939, vol. 104, Apr. 10, pp. 43–54). The author reviews the history of attempts to make pure sponge iron by low-temperature processes in the course of which he describes several types of furnaces used and the reasons for their failure. He refers in particular to the work of H. G. S. Anderson at Muskogee, who constructed a muffle furnace which used natural gas as both a heating fuel and a reducing agent. It produced 250–300 lb. of sponge iron in 24 hr. The author also describes plant erected by the Chrysler and General Motors Corporations for producing pure iron powder and the technique of sintering and briquetting the powder for the manufacture of bearings which do not require a lubricant.

Some Observations on Iron Powder Metallurgy. G. J. Comstock. (Iron Age, 1939, vol. 143, June 1, pp. 40–41, 64). In this discussion of the possibilities of developing in America the manufacture on a large scale of articles by the pressure-moulding of iron powder the author considers the cost and availability of this raw material. He shows that the present and probable future cost of manufacturing suitable iron powder is too high to encourage the installation of large plants for this process. He explains why Sweden is the only country producing iron powder on a large scale and at a price low enough to

encourage the development of the technique of pressure-moulding, and predicts that articles made by this process will soon be in active competition with cast and machined parts.

The Manufacture, Sale and Use of Iron and Steel in Great Britain. J. Henderson. (American Iron and Steel Institute, May 25, 1939). The author presents a comprehensive account of the history and economy of the iron and steel industry of Great Britain. He deals with his subject under the following headings: (*a*) History of invention and evolution; (*b*) the choice of steelmaking processes; (*c*) raw material resources; (*d*) blast-furnace and steel furnace practice; (*e*) chief characteristics of the producing districts; (*f*) research. He concludes his discussion with an account of the organisations for price-fixing, for regulating the conditions of sale at home and abroad and for widening the markets for steel.

The Metallurgical Monuments of the Ostmark. W. Schuster. (Stahl und Eisen, 1939, vol. 59, May 18, pp. 589–591). The author describes some of the old furnaces and other remaining monuments of a once thriving iron industry in the wooded valleys of the province of Styria. His article is illustrated with some photographs of charcoal furnaces at Vordernberg, Hieflau, Altenmarkt and Kendlbruck.

FOUNDRY PRACTICE

(Continued from pp. 67 A–76 A)

Heat and Power Economy in Foundries and Machine Shops with Special Reference to the Four Year Plan. W. Callenberg. (Giesserei, 1939, vol. 26, May 31, pp. 274–280). In this discussion of problems affecting the efficient utilisation of heat and power in foundries, the author gives some examples of methods of calculating the heat requirements and compares the costs of using generator gas and town gas for foundry purposes.

Efficiency in Crucible Melting. G. K. Eggleston. (American Foundrymen's Association, May, 1939, Preprint No. 3). The author explains the theories governing the transfer of heat and their relation to the efficient use of liquid and gaseous fuels for heating crucibles in a foundry.

Practical Approach to Job Analysis. G. J. Stegermerten. (American Foundrymen's Association, May, 1939). The author discusses the application of time-study methods in a foundry and makes various recommendations as to its use.

Accident Prevention in the Metal Industry. H. Jacobi. (Metallwirtschaft, 1939, vol. 18, June 9, pp. 485–488). The author describes some simple devices for the prevention of accidents in foundries and engineering shops.

Cupola Charging. A. W. Gregg. (Steel, 1939, vol. 104, May 22, pp. 56–57, 78). The author outlines a method of studying the transport of materials for charging cupolas with a view to ascertaining where economies can be effected and he makes some suggestions regarding the use of skip hoists for charging and electrically driven bogies for transporting raw materials.

Plastic Cupola Patching. R. E. Wilke. (American Foundrymen's Association, May, 1939, Preprint No. 12). The author decribes a cheap and satisfactory method of patching the lining in the melting zone of a cupola using a stiff mixture of white silica sand and fireclay mixed in a pug-mill.

Cupola Control. H. P. Hughes. (Foundry Trade Journal, 1939, vol. 60, May 18, pp. 399–402). The author explains the principles and practice followed in the working of the cupolas of the Grangemouth Iron Co. There are three cupolas at these works, two 4 ft. 9 in. and one 3 ft. 2 in. inside dia. at the melting zone. He deals in particular with the control of the air supply and has found from experience that the most suitable blast pressures for cupolas 24, 36 and 54 in. in diameter are 12–13, 15–17 and 19–22 in. of water respectively.

Predetermination of the Temperature in the Combustion Zone of a Cupola. A. Achenbach. (Giesserei, 1939, vol. 26, May 31, pp. 280–285). The author refers to his previous paper in which he explained the relation between the amount of heat produced by the gases in a cupola and velocity of their ascent in the shaft using Gay–Lussac's law. (*See* Journ. I. and S.I., 1932, No. II., p. 503 A). In the present paper, reversing his previous method of calculation, he shows the relation between the temperature in the combustion zone and the volume of air supplied, and applies this to the determination of the correct blower capacity for a particular cupola.

Production of Uniform Dense Structures in High Test and Alloy Iron Castings. M. A. Scott. (American Foundrymen's Association, May, 1939, Preprint No. 1). The author describes some experiments in the pouring technique at a foundry making high-duty and alloyed iron castings. From a study of both failures and successes the author concludes that the temperature of the sand surrounding the neck or junction between the riser and the casting has as much, if not more, bearing on the successful feeding of the casting than the temperature of the iron itself. As a result a technique of moulding with special regard to the position of the gates and risers was developed which has proved very successful for casting bushes, wheels and rolls.

Special Cast Irons. E. Morgan. (Swansea Technical College Metallurgical Society, Oct. 22, 1938). In this discussion of special cast iron, by which is meant any type of iron produced to meet specified conditions, the author deals first with problems relating to cupola practice. He considers next the metallographic characteristics of cast iron and their relation to the physical properties. In conclusion he gives some examples of high-strength and heat-resisting cast irons and describes the principles involved in their manufacture.

The Application of the Electric Arc Furnace for the Production of Grey Iron. G. Sper. (Giesserei, 1939, vol. 26, May 19, pp. 237–242). After enumerating the advantages and requirements of the electric furnace for melting iron in the foundry and a number of processes by which it can be used for producing grey iron, the author shows how its efficiency depends to a large extent upon the electrodes. He compares the properties of carbon and graphite electrodes. He discusses next the melting practice with particular reference to desulphurisation, and from this proceeds to a comparison of the melting and refining costs of the different processes. In conclusion he describes a method of making " synthetic " iron which consists of the direct melting of steel and iron scrap with additions of carbonaceous materials and ferro-alloys to produce the desired carbon, silicon and manganese contents.

Sixty Thousand Pound Per Square Inch Cupola Iron. E. L. Roth. (American Foundrymen's Association, May, 1939, Preprint

No. 14). The author describes in detail the method of charging and operating a cupola in order to produce an iron with a tensile strength of 60,000 lb. per sq. in. He presents tables showing the analyses and physical properties of sixty-four consecutive heats and discusses the effects of different forms of heat treatment on this iron. The average analysis of the iron with the above tensile strength and possessing good machining properties is: Silicon 1·60–2·20%, total carbon 2·95–3·25%, manganese 0·70–0·90%, phosphorus 0·12% max., sulphur 0·090% max., nickel 1·50–1·75%, chromium 0·15–0·35% and molybdenum 0·70–0·80%.

Steel Foundry Practice. (Machinery, 1939, vol. 54, May 18, pp. 203–207). An illustrated description is given of the new equipment at the Openshaw steel foundry of The English Steel Corporation, Ltd. A large variety of castings from a few ounces to 10 cwt. in weight are produced at these works. The melting equipment comprises a 30-cwt. Héroult electric-arc furnace, a 40-cwt. Birlec-Lectromelt furnace and a 5-cwt. Efco H.F. electric induction furnace. Sand-mixing machines, a sandslinger, a continuous core stove and magnetic and hydraulic moulding machines are also described.

Report of Steel Division Committee on Methods of Producing Steel for Castings. (Transactions of the American Foundrymen's Association, 1938, vol. 46, pp. 865–869). This report of the Steel Division Committee appointed by the American Foundrymen's Association to study methods of producing steel for castings enumerates some of the achievements in steel-making practice during 1937 reported in the technical literature of that year.

Modern Sand Testing. W. Y. Buchanan. (Institute of British Foundrymen: Foundry Trade Journal, 1939, vol. 60, May 11, pp. 385–388). The author describes first some tests on the expansion characteristics of rammed dry sand in an apparatus which permitted free expansion up to 0·005 in. after which the resistance of a spring was encountered. With this apparatus it was possible to apply a resisting force equal to about 75% of the cold dry-strength of the sand. He reproduces graphs which show that loads up to 75 lb. per sq. in. gradually reduced the total expansion from 0·022 to 0·008 in., but as about 0·006 in. free expansion occurred, the amount of expansion taking place against 50 lb. per sq. in. resistance was only 0·002 in. in the test-piece. As in dry-sand moulds which are subject to scab defects the resistance amounts to many hundreds of pounds per square inch, this resistance would easily counteract the expansion. In practice, a sand giving high expansion values in free expansion tests may not expand in the mould at all. This means that the total expansion of the grains can be fully accommodated within the rammed sand if resistance be present. In conclusion the author describes some tests made with additions of clay to the sand to see if this would reduce the expansion and eliminate scabs in the castings. He found that additions of 50% of

bentonite had very little effect on the total expansion and that it required as much as 80% to eliminate expansion as measured by free expansion tests. He is of the opinion that if scabbing has been eliminated by small additions of clay this has been due entirely to an increase in the green or dry strength and not to any modification of the sand's free expansion.

Synthetic Bonded Steel Molding Sands. C. W. Briggs and R. E. Morey. (American Foundrymen's Association, May, 1939, Preprint No. 6). With a view to determining the composition of a good moulding sand for steel castings the authors survey and compare the properties of a sand mix consisting of washed silica sand, bentonite and water, in the green and in the dry state, and examine the effect of using clay and organic binders. They found that a sand with excellent moulding properties could be obtained with a mixture of the above three constituents. They also studied the amount of gas evolved from moulding sand with different binders and found that less gas was evolved from sands containing bentonite than from those containing organic binders.

The Properties of Resin Bonded Cores. E. Pragoff, jun. (American Foundrymen's Association, May, 1939, Preprint No. 7). The author gives an account of his investigation of the properties of a number of core mixes in which resin preparations were used as the binder. His conclusions were : (1) Resin-bonded cores require special treatment, but when they are properly prepared they have excellent properties ; (2) the strength and hardness of the core depend upon the amount of binder in the mix ; (3) the smaller the grain size of the binder, the better is its effect ; (4) resin-bonded cores should be baked at 300—500° F. ; (5) they can be baked from 30 to 90 min. per inch of thickness without serious loss of strength ; (6) these cores are very suitable for castings which shrink considerably on solidification ; (7) increasing the moisture content up to 6–7% improves the compressive strength and the hardness but lowers the tensile strength ; (8) the application of resin binders enables many foundries to utilise their reclaimed sand ; and (9) resin-bonded cores lose little of their strength by being kept in storage.

The Hot Strength and Collapsibility of Foundry Sands. H. W. Dietert and E. E. Woodliff. (American Foundrymen's Association, May, 1939, Preprint No. 10). The authors investigated the strength of moulding sand and the tendency of oil-bonded cores to collapse at high temperatures. They studied both naturally and synthetically bonded moulding sands at temperatures from 60° to 2500° F. They found that up to 2000° F. the strength increased with increased moisture and clay contents. With regard to oil-bonded cores they found that the higher the permeability the greater the tendency to collapse, whilst increasing the clay content decreased this tendency.

Elements of the Petrographic Study of Bonding Clays and of the Clay Substance of Molding Sands. R. E. Grim. (American Foun-

drymen's Association, May, 1939, Preprint No. 23). The author reviews the methods now used for determining the composition and properties of clays with a view to ascertaining their utility as a binding material for moulding sands; these methods include the use of the microscope and X-rays, chemical analysis and dehydration.

Mineral Composition and Texture of the Clay Substance of Natural Molding Sands. R. E. Grim and C. S. Schubert. (American Foundrymen's Association, May, 1939, Preprint No. 26). The authors present an account of their investigation of the amount of clay present in samples of eight American moulding sands. This is known as the " clay substance " which is defined by the American Foundrymen's Association as that earthy portion of foundry sand which, when suspended in water, fails to settle 1 in. per min., and which consists of particles less than 0·02 mm. in dia. They also analysed the distribution of the clay substance according to the size of grain, and found that the irregular distribution accounted for the absence of any close relation between the amount of clay substance and the physical properties of natural moulding sands.

Quality Pattern Equipment for Diesel Engine Tractor and Road Machinery Castings. J. E. Kolb. (American Foundrymen's Association, May, 1939, Preprint No. 27). The author describes the principles and practice of pattern making employed at the foundry of the Caterpillar Tractor Co.

Castings for the British Gas Industry. F. Whitehouse. (Foundry Trade Journal, 1939, vol. 60, May 25, pp. 423–427; June 1, pp. 442–444). The author describes the foundry technique (with particular reference to moulding) employed in the production of cast-iron retorts, purifier boxes, heaters, pipes and valves used by the gas industry.

Some Jobbing Problems. F. G. Jackson. (Foundry Trade Journal, 1939, vol. 60, Mar. 9, pp. 212–214; June 1, pp. 440–441; June 8, pp. 481–482). The author describes the moulding and casting technique employed in the production of castings for hydraulic cylinders, rams, jacketed cylinders, rotary and screw pump bodies, small rolls, capstan boxes and water columns used for filling locomotives.

Molding Equipment for the Miscellaneous Production Foundry. W. J. Jennings. (American Foundrymen's Association, May, 1939). The author describes the organisation and equipment of a modern foundry producing large numbers of miscellaneous castings. He deals in particular with the control of the moulding sand and the use of sandslingers.

The " Sandontap " System of Moulding. (Foundry Trade Journal, 1939, vol. 60, June 8, pp. 484–485). A brief description and drawings are presented of a new plant for supplying sand to moulds. The plant illustrated consists of a battery of four vertical hoppers to which the sand is fed by an overhead conveyor belt. There is an electrically driven blower at the base of each hopper.

The delivery side of each hopper consists of an articulated tubular arm to which may be attached a long length of flexible tube. To mould, the delivery end of this tube is simply moved horizontally over the box until the stream of sand has filled it. It is claimed that a mould made with this equipment has a high degree of permeability and that the sand on a vertical surface is just as hard as on a horizontal one. About 225 cu. ft. of free air at a pressure of 70–90 lb. per sq. in. are required to deliver 1 ton of sand. The equipment has been used with success to deliver sand through 50 ft. of 1-in. dia. tube.

Hints on Moulding and Preparation of Castings for Enamelling. R. B. Schaal. (Transactions of the American Foundrymen's Association, 1938, vol. 46, pp. 769–780). The author discusses the factors to which attention should be paid in the design and manufacture of castings which are to be enamelled. He stresses the following points : edges should be rounded, the thickness should be as uniform as possible, large flat surfaces should be avoided and particular attention should be paid to the moulding sand.

The Shearing of Malleable Iron Gates. S. D. Martin. (American Foundrymen's Association, May, 1939, Preprint No. 21). The author discusses and compares methods of removing gates from malleable iron castings. These methods include "snubbing," grinding, shearing, milling and broaching. The author devotes particular attention to shearing, which is a rapid and economical method, and discusses the design and material used for shear blades and casting holders.

Castings for Machine Tools. P. Dwyer. (Foundry, 1939, vol. 67, May, pp. 36–39, 98). The author describes the plant and foundry technique employed at the Cincinnati Milling Machine Co. which produces about 45 tons of grey iron castings per day. The castings are for parts of machine tools for centreless grinding, lapping, broaching, automatic profiling and die sinking and they vary in weight from a few ounces to $4\frac{1}{2}$ tons.

Some Tests on the Effectiveness of Water Blast under High Pressure for Cleaning Castings. R. Webster. (American Foundrymen's Association, May, 1939). The author describes an investigation of the abrasive effect of a high-pressure jet of water and sand upon specimens of steel plate. This was undertaken with a view to obtaining more knowledge of the application of this process for cleaning castings and removing cores. The tests were carried out on pieces of copper-bearing steel plate $6 \times 6 \times \frac{5}{16}$ in. which were set up so that the jet of water and sand issuing from an orifice 0·19 in. in dia. impinged on the centre of the plate at an angle of 45°. Two kinds of sand were used, particulars of which are given. Each test lasted 8 min. and about 60 lb. of sand was carried per min. Tests were made with the orifice clamped at 8, 16 and 36 in. from the plate and pressures of 800, 1000 and 1200 lb. per sq. in. were tried. The plates were weighed before and

after the tests to determine the loss by abrasion. The author found that there was little difference in the abrasion with the orifice 8 in. and 16 in. from the plate, but at 36 in. the loss in weight was much less. The differences were much less noticeable using a coarse sand than with a fine sand. At 36 in. the "spread" of the jet caused the abrasion to be less deep and to spread over a wider area than at shorter distances.

Apply Modern Cleaning Methods. F. Daniels. (Foundry, 1939, vol. 67, May, pp. 44–46, 92). The author describes the equipment recently installed by The Waterbury Farrel Foundry and Machine Co., Connecticut, for the cleaning of castings. The equipment includes tumbling machinery, steel shot blasting equipment, dust arresters and plant for removing cores from large castings. The removal of cores is done with a jet of water from a 1½-in. nozzle at a pressure of 400 lb. per sq. in. All the equipment is housed in a separate building.

Effect of Superheating on Castability and Physical Properties of Cast Irons of Different Carbon Contents. N. A. Ziegler and H. W. Northrup. (American Foundrymen's Association, May, 1939, Preprint No. 17). The authors describe an investigation of the effect of superheating grey iron on its castability. A series of irons were used containing carbon 3·24%, 3·00%, 2·50% and 2·25%, and the tests were made by heating the iron in a H.F. induction furnace to temperatures ranging from 1430° to 1650° C. and casting into spiral and standard test-bar moulds as developed by the Bureau of Standards. In some cases the casting temperature was the same as the superheating temperature and in other cases the iron was allowed to cool a little before casting. The authors came to the following conclusions: (1) The castability was improved by increasing the carbon content, the pouring temperature and the superheating temperature; (2) the transverse bend strength, Brinell hardness, tensile strength and limit of proportionality are increased by decreasing the carbon content; and (3) super-heating tended to eliminate free ferrite, to refine and localise graphite flakes and to break up dendrite formations.

The Effect of Melting Conditions on Gas Unsoundness in Metals. G. L. Bailey. (Institute of British Foundrymen (International Foundry Congress), London, June, 1939, Preprint No. 668). A general discussion of the occurrence of unsoundness in cast metals due to evolution of gases on solidification and of the effect of melting conditions on the absorption of such gases. Two types of gas unsoundness are clearly differentiated, the first due to the solution of an elementary gas (*e.g.*, hydrogen) in the molten metal and its evolution on solidification, and the second due to the reaction on solidification of two constituents in solution in the melt (*e.g.*, hydrogen and oxygen) to form an insoluble gas.

PRODUCTION OF STEEL

(Continued from pp. 77 A–81 A)

Steel Production in Scotland. Part I. Dalzell Steel Works, Motherwell. (Electrical Times, 1939, vol. 95, May, 18, pp. 731–733). An illustrated description is given of the 32-in. bar mill, the bar and rod mill, the blooming mill, the cooling bed, shears and lifting magnets at the Dalzell Works of Colvilles Ltd. The electrical equipment receives particular attention in this account.

The Brackridge Plant of the Allegheny Steel Company. (Iron and Coal Trades Review, 1939, vol. 138, June 9, pp. 1002–1004). An illustrated description is given of the Brackenridge Works of The Allegheny Steel Co. This company is now in the combine known as The Allegheny Ludlum Steel Corporation. The plant comprises seven electric and ten open-hearth furnaces ; blooming, strip, sheet, merchant, plate and tube mills ; seamless tube works ; iron and steel foundries, and a lamination and stamping department.

The Control of the Quality of Output of a Modern Basic Open-Hearth Steelworks Producing Plain Carbon Engineering Steels. R. G. Heggie. (Journal of the Chemical, Metallurgical and Mining Society of South Africa, 1939, vol. 39, Feb., pp. 216–251). The author describes the methods for the mechanical and metallographical control of the quality of the plain carbon steels produced at the Iscor Steelworks, Pretoria. He refers to the relationship between analysis and tensile strength, and reproduces and explains the control chart for structural steel used at these works. He shows by means of " recovery curves " that rolling strains induced in rail steels affect the elongation. He illustrates by an experiment the differences in light conditions between South Africa and Europe. He explains some defects which are liable to occur in works' practice, how these are detected and eliminated and concludes by discussing some of the defects which occur in steel sheets.

The Metallurgical Reactions in the Recuperative Steel Melting Furnace. M. Burchardt and M. Paschke. (Stahl und Eisen, 1939, vol. 59, May 11, pp. 565–572). The authors consider the efficiency of the recuperative open-hearth furnace the design and thermal characteristics of which have already been described by G. Hofmann and M. Paschke (*see* p. 13 A). They then discuss in detail the theory of the metallurgical reactions with particular reference to the experience gained from six melts which were very carefully studied. They are of the opinion that the use of this new type of furnace will enable a better control of the process to be obtained than is at present possible with the usual type of open-hearth furnace, and that it may also be possible to produce steel with it at less cost.

Control of the Basic Open-Hearth Process by the Method of Petrographic Analysis of the Slags. P. V. Umrikhin and V. V. Lapin. (Metallurg, 1938, No. 11, pp. 72–79). (In Russian). Open-hearth heats involving the following special operations were carried out: (1) Heats in which the slag was run off during the dephosphorising period and was replaced after that period by a slag of normal or increased basicity. (2) Heats without removal of the slags, which during the progress of the heat had an increased alumina content. (3) Heats under slags with increased alumina and magnesium oxide contents. Changes in the composition of the metal and the slag as well as the petrographic composition of the latter during a heat carried out by the first method are described in some detail. From these observations as well as from those made on heats by the second and third methods, some conclusions are derived regarding the connections between the constitution of the slag and its petrographic composition. It seems possible that the latter may be used as a quick check on the composition of the slag and hence indirectly on the metal during the progress of a heat. A number of micrographs illustrating the various petrographical constituents of slags are reproduced.

The Reactions between Aluminium and Oxygen in Iron Melts. H. Wentrup and G. Hieber. (Technische Mitteilungen Krupp, Forschungsberichte, 1939, vol. 2, May, pp. 47–58). The equilibrium between oxygen and aluminium in iron melts was found to be dependent on the deoxidation constant $K = (Al)^2 \times (O)^3$. The values of K are $7{\cdot}5 \times 10^{-9}$ at 1700° C., $9{\cdot}0 \times 10^{-11}$ at 1600° C., and $1{\cdot}6 \times 10^{-12}$ at the solidification temperature. The laboratory furnace used for the experiments is described in detail. The iron used contained 0·05% of carbon, 0·01% of silicon, 0·12% of manganese, 0·01% of phosphorus, 0·014% of sulphur, 0·10% of copper, 0·06% of nickel, 0·02% of chromium and 0·014% of arsenic. Oxide was added in the form of ferrosoferric oxide produced by oxidation of carbonyl iron, and the aluminium used was of 99·1% purity. The authors also examined micrographically the inclusions formed in irons by the addition of aluminium to melts containing oxygen.

The Optimum Contour of an Electric Furnace Hearth. G. Klyushin and V. Anosov. (Stal, 1938, No. 10, pp. 29–31). (In Russian). The authors present a short mathematical consideration of the optimum shape of the hearth of an electric arc furnace and compare their conclusions with those of other investigators and with actual furnace practice. They are of the opinion that a durable shape would be a hyperboloid the asymptotes of which are inclined at an angle of 35–40°.

Graphite Electrodes. J. Forssell. (Teknisk Tidskrift, 1939, vol. 69, May 13, Kemi, pp. 33–35). (In Swedish). The author discusses the physical and electrical properties of graphite and amorphous carbon electrodes for use in electric furnaces working at

temperatures above 1200° C. He refers to Arnfelt's investigation of an amorphous carbon electrode one end of which had been heated sufficiently to convert it completely to graphite while the other end was kept cold; this showed that graphitisation is nothing else than a process of crystallisation, but the crystals are much too small to be visible under the microscope. Further research has proved that the densest arrangement of the carbon atoms occurs in the carbonisation of volatile organic matter such as pitch, and carbon produced in this way is therefore the most suitable material for making electrodes. The author's comparison of the two kinds of electrodes shows that those made of graphite offer distinct advantages in electric arc furnaces, whilst the cheaper carbon electrode is more economical in reduction furnaces in which the electrodes are actually in contact with the charge.

Production of Stainless Acid-Resistant Steel by the Process Used at the Kirov Works. V. Zamoruev. (Stal, 1938, No. 10, pp. 31–37). (In Russian). The author briefly reviews earlier methods used for the production of chromium and stainless steels. He then describes the method used at the Kirov works which is based on an earlier process developed by Kovarsh. The principal features of this are: (1) A normal charge for stainless steel heats involving oxidising is used and the oxidising period is shortened by keeping the carbon down to 0·3–0·4% after melting. (2) The charge is melted with the addition of lime. (3) The oxidising process is conducted under a ferrous-oxide/lime slag. (4) The removal of slag. (5) Preliminary deoxidation of metal with an aluminium-manganese-silicon alloy. (6) Addition of previously heated ferro-chromium in two or three large batches with the electrodes raised. (7) The metal is refined under a semi-acid slag which is partly "self-formed" and partly obtained by additions of small amounts of burnt fireclay, the total quantity of slag being kept low. (8) The slag is deoxidised by the addition of finely ground screened ferro-silicon. (9) The composition and temperature of the steel are controlled and the heat is tapped. Practical observations on the working of this process are recorded. It was found that the magnesite lining stood up very well to the semi-acid slag, while at the same time the small amount of slag present required a shorter length of arc to maintain the requisite temperature of the steel, and this in turn reduced the temperature to which the roof was subjected. The number of slag inclusions in the steel was low.

Technology of the Production of Stainless Steel *EYalT*. V. Leykin. (Stal, 1938, No. 10, pp. 37–39). (In Russian). The author discusses briefly the production of stainless steel *EYalT* which is high in chromium with a small addition of titanium, and then gives concise instructions for the melting, teeming, and rolling of a 6-ton heat of this steel.

The Rôle of Magnesia and Its Interaction with Ferrous Oxide in Basic Open-Hearth Slag. V. V. Lapin. (Metallurg, 1938, No. 11,

pp. 68–71). (In Russian). Petrographic examination of basic open-hearth slags (taken during dephosphorising and during the boil) during the course of a heat showed that magnesia introduced as a result of attack on the furnace lining by the slag, does not enter into the composition of the silicates, though to some extent it is present in the spinel. The greater part of the magnesia in the molten slag is free in the form of periclase. The latter if present in large grains increases the viscosity of the slags. Ferrous oxide may be present (in amounts of 2·5 to 78% by weight) in solid solution in the periclase. A definite connection between the refractoriness of the periclase and the ferrous oxide/magnesia ratio in the slag has been established. The presence of large amounts of ferrous oxide in periclase as a result of a very large amount of ferrous oxide in the slag may lower the amount of active ferrous oxide in the latter, which in addition to increasing the viscosity of the slag, will result in a decrease of the rate of oxidation of the carbon.

Vanadium Oxides in Converter Slags. A. N. Morozov. (Metallurg, 1939, No. 1, pp. 15–27). (In Russian). The investigation was carried out on synthetic basic (CaO) and acid (SiO_2) slags containing V_2O_5, V_2O_4 or V_2O_3, both pure oxide mixtures and mixtures containing iron oxides (prepared by melting slag in contact with molten iron under an atmosphere of nitrogen) were studied. Some indications were obtained of the existence of compounds of lime with vanadium sesquioxide ($2CaO.V_2O_3$ and possibly $CaO.V_2O_3$) which would confirm the acidic behaviour of V_2O_3 in melts. These compounds are very considerably dissociated in the molten state. Compounds of lime with V_2O_4 cannot exist in the molten state owing to conversion of the V_2O_4 to V_2O_5, V_2O_3 and their compounds. None of the three oxides of vanadium form any compounds with silica and their mutual solubility is slight. Metallic iron at 1600–1650° C. in a neutral atmosphere reduces the higher oxides of vanadium to the sesquioxide in both acid and basic slags. It is probable that in basic slags vanadium is present in the form of considerably dissociated compounds of V_2O_3 with FeO and CaO (possibly also with MgO and MnO). In acid slags the vanadium is mainly present as free V_2O_3. Higher oxides may be formed by oxidation of the V_2O_3 under favourable conditions.

Investigation of the CaO-V_2O_5 System. A. N. Morozov. (Metallurg, 1938, No. 12, pp. 21–28). (In Russian). The melting-point curve of the CaO-V_2O_5 system was determined by thermal analysis for the range 0–50% of CaO. Microscopic examination proved the existence of three chemical compounds, the mono-, di-, and tricalcium vanadates having the following formulæ and decomposition temperatures, $CaO.V_2O_5$, 778° C.; $2\ CaO.V_2O_5$, 1015° C. and $3CaO.V_2O_5$, 1380° C. respectively. The monocalcium vanadate and the vanadium pentoxide form a eutectic at 7·5–8·0% of CaO and 92·5–92·0% of V_2O_5 with a melting point of 618° C.

Ingot Mold Insulation. F. M. Ritts. (Steel, 1939, vol. 104, May 29, pp. 46, 61). The author states the advantages of a new insulating material for use on the top of an ingot immediately it is poured in order to reduce the amount of pipe. The material consists of cork granules coated with a refractory clay. It is very light, weighing only 25 lb. per cu. ft. and it is usually applied by throwing a paper bag of the material on the ingot top immediately after pouring. Tests have shown that a 2-in. layer of this material on a 4-ton ingot of killed steel kept the metal molten for 65 min. as compared with 12 min. when sand was used. Other advantages claimed for it are that " after-pouring " is facilitated and that the steel does not absorb any carbon from the material.

The Structure of Rimming Steel Ingots. A. Hultgren and G. Phragmén. (Archiv für das Eisenhüttenwesen, 1939, vol. 12, June, pp. 577–594). A translation into German of a paper which appeared in Jernkontorets Annaler, 1938, vol. 122, No. 8, pp. 377–453. (*See* Journ. I. and S.I., 1939, No. I., p. 214 A).

Factors Influencing the Surface of Alloy Steel Ingots and the Rôle of the Ingot Mould Wash. A. Pelevin. (Stal, 1938, No. 8–9, pp. 28–31). (In Russian). In this investigation of the surface of ingots the factors considered included the chemical composition and physical state of the metal, the temperature and the rate of teeming, the effect of deoxidisers such as aluminium, titanium, silicon, the method of teeming, quality and state of the moulds and finally the effect of the mould wash or coating. Some data obtained at the Elektrostal works regarding mould washes are presented. Altogether twenty types of coating were tried, and pitch coke was found to be the best. The results are evaluated and arranged in order of merit using a system of awarding marks (marks awarded for quality of ingot surface from 0 to 4) and a percentage basis. Assuming the total effect of the factors affecting the surface quality of ingots, slabs, &c. to be 100, the relative importance of the individual factors is shown in the following table :

Type of steel and degree of deoxidation . . .	10
Temperature and rate of teeming	25
Deoxidisers such as aluminium, titanium, silicon, &c.	15
Method of pouring (syphon or top-pouring) . .	10
Soaking-pit practice and quality and state of moulds	15
Mould wash	20
Other factors	5
Total	100

ROLLING-MILL PRACTICE

(Continued from pp. 86 A–87 A)

Elastic Compression of Rolling-Mill Rolls. I. M. Pavlov and Y. S. Gallay. (Metallurg, 1938, No. 1, pp. 79–86). (In Russian). Earlier literature on the radial compression of rolls is first briefly considered and a method of directly measuring the radial compression of rolls is developed. The deformation of rolls pressed into contact is then determined by measuring the width of the imprint on the lower roll made by the upper roll which was coated with soot. Both static and dynamic experiments were performed to investigate the deformation of the rolls when a strip of uniform thickness was placed or rolled between them. In the latter case it was found that lateral spreading of the strip was confined to its edges owing to their greater reduction in thickness due to the radial compression of the rolls. There is a parabolic relation between pressure and the radial compression of the rolls. Everything which tends to increase the pressure on the rolls will cause an increase in the irregularity of the lateral distribution of the reduction in thickness. This irregularity is reduced by rolling annealed metal and by using small reductions per pass, polished rolls and efficient lubrication. Radial compression decreases with the diameter of the rolls.

Rolling-Mill Plant of the Ford Motor Company at Rouge Works. (Iron and Coal Trades Review, 1939, vol. 138, June 2, pp. 956–957). An illustrated description is given of the new 44-in. blooming mill recently installed at the Dearborn Works of The Ford Motor Co. This mill is designed to take either 2-ton fluted alloy ingots or slab ingots weighing up to 8 tons and roll them to slabs for feeding the new strip mill. The electrical equipment, shears, scale breaker and auxiliary equipment are also described.

A. I. & S. Ltd. Kembla Works Billet & Sheet Bar Mill. J. A. Spence. (Broken Hill Proprietary Review, 1939, vol. 16, Apr., pp. 16–17). The author describes the finishing procedure at the new sheet bar and billet mills of Australian Iron and Steel Ltd. at Kembla. (*See* p. 19 A).

Sheet Rolling in Australia. J. C. F. Lysaght. (Broken Hill Proprietary Review, 1939, vol. 16, Apr., pp. 10–13). The author points out that in countries in which there is insufficient demand for steel sheets to justify the installation of continuous wide strip mills the process of sheet production has been speeded-up and developed mainly by applying mechanical handling methods. At Lysaght's Newcastle Works Proprietary Ltd. there is a sheet mill of this type which the author describes and illustrates.

New Tin-Plate Mill. (Steel, 1939, vol. 104, May 22, pp. 66–68, 80: Iron Age, 1939, vol. 143, May 25, pp. 40–42). A description is given of the 38-in. tinplate mill at the Irvin Works of the Carnegie-Illinois Steel Corporation which is designed for a production of 100,000 tons per annum.

Modern Methods of Producing Sheets and Tinplate with Special Reference to Semi-Continuous and Continuous Hot and Cold 4-High Mills and Processes. J. Malborn. (Swansea Technical College Metallurgical Society, Dec. 10, 1938). The author reviews progress which has been made during the last twelve years in the machinery and processes for the rolling of steel sheet and strip.

Development of Cold-Rolling Practice. A. J. Castle. (Iron and Steel Engineer, 1939, vol. 16, May, pp. 26–29). The author presents a brief historical survey of the development of the cold rolling of metals, concluding with some particulars of the mills now in use at the works of the Inland Steel Co.

Irvin Works—Cold Mills Heavily Powered. (Blast Furnace and Steel Plant, 1939, vol. 27, Apr., pp. 366–369). Particulars are given of the rolling mill for the cold reduction and finishing of steel strip and sheet up to $\frac{1}{4}$ in. thick, up to 77 in. wide and in coils up to 54 in. in outside diameter or in sheets up to 32 ft. long. The generating sets, mill motors and annealing furnaces are also described. This mill forms part of the plant at the Irvin Works of the Carnegie-Illinois Steel Corporation. (*See* Journ. I. and S.I., 1939, No. I., p. 157 A).

Acceleration of Tandem Cold-Strip Mills. T. R. Rhea and M. J. Melling. (Iron and Steel Engineer, 1939, vol. 16, May, pp. 30–40). In this mathematical discussion the authors consider the problem of tension variation between stands during the acceleration and de-acceleration of a modern high-speed tandem cold-strip mill. They also make some general recommendations regarding the selection of motors for such a mill.

Frequency Relays and Motor Acceleration for Steel Mill Control. D. C. Wright. (Iron and Steel Engineer, 1939, vol. 16, May, pp. 62–71). The author discusses the factors affecting the design of a frequency relay for accelerating and de-accelerating rolling-mill motors.

Electric Motor Pinion Drives for Rolling Mills. K. Schulze-Allen. (Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns, 1939, vol. 7, Apr., pp. 47–57). The author describes the design and manufacture of some modern rolling-mill drives. He points out that the pinions are usually made of cast iron with the rim and teeth of a tempered silicon-manganese steel shrunk on. The pairs of pinions are enclosed in cast-iron housings with oil-tight covers to the bearings which are plain with forced-feed lubrication. He describes some oiling systems and an elastic coupling the turning moment of which is adjustable.

HEAT TREATMENT

(Continued from pp. 89 A–94 A)

The Improvement of Metal Surfaces by Diffusion. (Metallurgist, 1939, vol. 12, Apr., pp. 20–22). The mechanism of the diffusion of one metal into the surface of another in order to obtain increase hardness or resistance to corrosion is explained, and the importance of both metals forming solid solutions with one another without the presence of an intermetallic compound is stressed. Three possibilities exist : (1) Both metals form a continuous series of solid solutions with one another ; only solid solution occurs, therefore, on diffusion. (2) Both metals, besides forming solid solutions α and β, also possess a range in which the two phases α and β exist together in the structure ; these, on diffusion, show a sudden change in concentration at the edge of the region of solid solution. (3) Both metals, besides forming solid solutions, form intermetallic compounds, so that as many layers may exist between them as there are phases at the temperature of the experiment.

Gas Nitro-Carburising. V. I. Prosvirin. (Metallurg, 1938, No. 11, pp. 82–84). (In Russian). As earlier work by the author had shown that the diffusion of carbon into the surface of iron or steel was accelerated by the presence of nitrogen, he has since developed a process in which the parts to be treated were subjected to the alternate action of a current of ammonia and of a hydrocarbon gas while being heated to a suitable temperature. In this process a case similar to that obtained by cyaniding was formed, the intermittent treatment for 10–20 min. at a time with ammonia introduced nitrogen into the iron, and lowered the temperature of diffusion of the carbon. The author points out that the " dry cyaniding " treatment recently introduced by the Surface Combustion Corporation appears to resemble this process. Some experimental figures for the depth and hardness of the case obtained by this method on different steels are given and some micrographs illustrate the structure of the case. The possibility of using a mixture of ammonia and hydrocarbon gas is mentioned.

Causes of the Deformation of Parts During Nitriding. G. F. Kosolapov. (Metallurg, 1938, No. 11, pp. 88–93). (In Russian). The various causes which have been suggested for the deformation of nitrided parts are reviewed and discussed. The author describes his experiments in which strips of different steels were subjected to nitriding on one side (the other side being protected by nickel-plating) under different conditions and their deformation studied. The results indicated that dimensional changes and distortion during

nitriding are caused by the increase in volume of the case as a result of the introduction of the nitrogen and not by the difference in the coefficients of expansion of case and core. Nitriding at higher temperatures increases the total and plastic deformation and reduces elastic deformation. Heating the nitrided part to above the nitriding temperature results in a change in the amount of deformation. The amount of distortion during nitriding appears to depend on the composition of the steel and on the increase in hardness produced by nitriding.

The Surface Decarburisation of Steel and the Problem of Diffusion. T. Berglund. (Jernkontorets Annaler, 1939, vol. 123, No. 2, pp. 54–113). (In Swedish). The author describes an investigation of the surface decarburisation of steel in bright annealing mixtures of carbon monoxide, carbon dioxide and nitrogen in the temperature range 730–920° C. A special apparatus was devised so that extremely accurate control of the composition and rate of flow of the gases could be maintained. Over 180 specimens of steel were tested and the author presents tables in which the carbon content of the steel at case depths from 0·20 to 1·00 mm. in stages of 0·10 mm. are shown for all the specimens. The general conclusions drawn from these results are as follows: (1) The rate of chemical reaction between the gas and the carbon of the steel at first increases very fast as the velocity of the gas increases, but approaches a limit value at high velocities of the gas. At 920° C. the maximum rate of reaction seems to be approached at a velocity of the gas of 70 cm. per sec. (2) The loss in weight due to decarburisation is, when all other experimental conditions are kept constant, proportional to the original carbon content (or probably more strictly to the carbon activity) of the steel. Consequently the rate of the reaction cannot be independent of the carbon content in the steel as has been previously stated. (3) The loss in weight due to decarburisation is independent of the content of manganese in the steel within the limits used in commercial carbon steels. (4) On bright annealing in a gaseous mixture of decarburising character, the maximum amount of carbon carried away is in the first place determined by the rate of reaction between the annealing atmosphere and the steel, and depends only to a slight extent on the rate of diffusion of carbon within the steel. The rate of diffusion may, however, be of greater importance for steels very low in carbon. (5) To obtain the least possible amount of decarburisation in bright annealing, the amount of carbon dioxide and carbon monoxide should be brought to a low value keeping the proportions between these gases as close as possible to the requirements for equilibrium conditions with the steel. (6) The carbon content at the surface of the steel decreases rapidly at first on annealing under decarburising conditions, but the decrease of carbon soon slows down, and it will take a considerable time (more than 6 hr. in the present experiments at 920° C.) for the surface to attain a carbon content anywhere in the neighbourhood of the value

corresponding to equilibrium with the gas. For the purpose of calculating the diffusion constant of carbon in steel it cannot be assumed, even as a rough approximation, that the carbon content in the surface of the steel approaches equilibrium with the gas in infinitely short time; this has been the general belief in several earlier investigations. (7) It has been shown that the character of the steel (fine or coarse grained) has a considerable influence on the decarburisation tendency of the steel, especially in the approximate temperature range of 750–850° C. When comparing fine grained steels with coarse grained ones on the basis of equivalent analysis, the former show a greater tendency to decarburise. After 6 hr. annealing under strongly decarburising (but still bright annealing) conditions at 780° C., fine grained steels in these experiments have lost 50% more carbon by weight than corresponding coarse grained steels. The difference is assumed to be caused by the catalytic effect of the finely dispersed alumina in the fine grained steels. The alumina may speed up the reaction rate between the gas and the carbon in the surface of the steel. (8) There are reasons for believing that the rate of diffusion of carbon in steel, when in the γ state, increases with the carbon content. (9) Comparatively small amounts of alloying elements of strongly carbide-forming character seem to slow down the diffusion of carbon within the steel. When such steels are decarburised, a much steeper carbon gradient is obtained near the surface. The low carbon content at the surface may, on microscopic examination, give the impression of heavier decarburisation than does a corresponding steel not alloyed. In reality the straight carbon steel may have lost a greater amount of carbon determined by weight, although the carbon content at the surface is higher.

Heat-Treatment Plant. (Aircraft Production, 1939, vol. 1, June, pp. 274–275). A description is given of some heat-treatment furnaces used in the aircraft industry. These include: a natural-draught, gas-fired recuperative furnace, electric carburising and reheating furnaces, an electric enamelling oven, a gas-fired salt bath for annealing and normalising, and a Ripoche tipping furnace for the heat-treatment of long wing-girders.

Blowpipe-Annealing High-Chromium Steel. W. D. Wilkinson. (Welding Journal, 1939, vol. 18, May, Supplement, p. 181). The author describes how the ductility of welds in steels containing up to 24% of chromium can be greatly improved by a form of normalising which consists of heating with the oxy-acetylene flame to a temperature of 650–750° C., holding at this temperature for a few minutes and allowing to cool in still air.

Some Factors Involved in Hardening and Tempering Grey Cast Iron. G. A. Timmons, V. A. Crosby and A. Herzig. (American Foundrymen's Association, May, 1939, Preprint No. 24). The authors describe their investigation of the effects of various forms of heat treatment on the properties and structure of specimens of unalloyed grey iron and grey iron containing small percentages

of chromium, nickel and molybdenum. From the results obtained the authors conclude that : (1) graphitisation of unalloyed pearlitic cast iron takes place rapidly at temperatures from 1400° to 1450° F. ; (2) the combined carbon content of the iron in the "as cast" condition has no effect on the carbon concentration in the austenite at the instant of quenching ; the controlling factors in order of importance are : the temperature from which the iron is quenched, the time during which the iron is kept at this temperature, and the chemical composition ; (3) the addition of alloys is a useful means of controlling the rates of graphitisation and transformation, and the resulting degree of hardness.

Oil Well Pumps. (Steel, 1939, vol. 104, May 29, pp. 54–56). A description is given of the heat-treatment procedure for "sucker rods." These are nickel-molybdenum steel rods 25–30 ft. long and $\frac{5}{8}$–1 in. in dia. used for transmitting the power from the engine at the top of an oil well to the pump at the bottom. The exact form of heat treatment for each individual delivery of rods is determined by "pilot treating." This consists of normalising and drawing a number of sample bars each at different temperatures and comparing the physical properties of the bars after treatment. That form of treatment which produces the best properties is then applied to the whole batch. The heat treatment consists of normalising at 1550–1650° F. with subsequent heating to 1050–1225° F. and quenching.

WELDING AND CUTTING

(Continued from pp. 95 A–97 A)

Coatings and Fluxes in the Welding of Steel. W. Spraragen and G. E. Claussen. (Welding Journal, 1939, vol. 18, May, Supplement, pp. 153–165). The authors review the literature to Jan. 1, 1938, on the composition and functions of the coating on electrodes used for electric welding. A bibliography of 144 references is appended.

Data on the Spot Welding of Low Carbon Steel. W. F. Hess and R. L. Ringer. (Welding Journal, 1939, vol. 18, Apr., Supplement, pp. 113–115). This paper constitutes a progress report by the Welding Research Committee of Engineering Foundation on work carried out at the Rensselaer Polytechnic Institute Welding Laboratory. The previous report dealt with the welding of stainless steel sheet; (*see* Journ. I. and S.I., 1939, No. I., p. 104 A). The authors now present data regarding the spot welding of hot rolled, annealed and pickled mild steel sheet 0·029 in. thick. From their investigations they arrive at the following conclusions: (1) The optimum pressure on the electrode tips is 15,000 lb. per sq. in. (2) from 6 to 12 current cycles are required for material 0·029 in. thick and the currents corresponding to these cycles are 13,500 and 12,000 amp. respectively; and (3) with flat electrode tips the indentation produced in welding is a clear index of the dividing line between the correct and excessive values of current, for there is a marked increase in indentation immediately the optimum current value is exceeded.

The Effect of Phosphorus on the Welding of Steel. W. Spraragen and G. E. Claussen. (Welding Journal, 1939, vol. 18, Apr., Supplement, pp. 123–130). The authors review the literature to July 1937 on the effect which the phosphorus in steel has on its welding properties.

Welded Low Alloy Steels. A. E. Gibson. (Welding Industry, 1939, vol. 7, June, pp. 175–178). The author describes some examples of the replacement of heavy castings by welded, rolled, low-alloy steel which have resulted in the saving of weight and longer life. The examples include mechanical grabs and gas-producer bodies.

The Effect of Normalising Fine Grained Low-Alloy Steel (St 52) before Welding. R. Wasmuht. (Welding Journal, 1939, vol. 18, May, Supplement, pp. 165–166). An abridged English translation of an article which appeared in Stahl und Eisen, 1939, vol. 59, Feb. 23, pp. 209–212. (*See* Journ. I. and S.I., 1939, No. I., p. 285 A).

Welding of Chromium Steels. H. Cornelius. (Zeitschrift des Vereines deutscher Ingenieure, 1939, vol. 83, June 10, pp. 707–713). An abbreviated translation into German of Spraragen and Claussen's review of the literature on the welding of chromium steels. (*See* Journ. I. and S.I., 1938, No. II., p. 231 A).

Manufacture of Composite Metals by Carbon Arc Welding. R. E. Kinkead. (Welding Journal, 1939, vol. 18, Apr., pp. 205–209). The author describes an electric welding process by which a coating of special steel can be applied to sheets of ordinary carbon steel. (*See* p. 24 A).

Modern Methods and Modern Steels in Welded Ship Constructions. P. Schoenmaker and I. G. De Rooy. (Welding Journal, 1939, vol. 18, May, pp. 273–276). The authors review the advantages of, and the present state of development in the application of electric welding to shipbuilding, with particular reference to the increased use of high tensile steel.

Elimination of Rail Joints from Steam and Electric Railway Track by Arc Welding. D. B. Hunt. (Welding Journal, 1939, vol. 18, Apr., pp. 228–234). After enumerating the advantages of welding rail joints instead of using the usual fishplate joint, the author describes in detail the welding technique employed for the manual electric welding of rails. His description includes the heat treatment before and after the actual welding operation.

Testing the Physical Properties of Welds. O. H. Henry and G. E. Claussen. (Welding Journal, 1939, vol. 18, May, pp. 288–294). The authors differentiate between four classes of tests for electric welds. These are: (1) Tests of the operator's ability; (2) tests of the materials, equipment and technique; (3) tests of the properties of a welded joint; and (4) tests to obtain information relating to design. They then describe the methods of applying tension, bend, shear, torsion, notched-bar impact, fatigue, hardness and corrosion tests to welds. In conclusion they give a list of the physical properties which welded joints should have in order to comply with the usual American requirements.

Contribution to the Study of the Contraction and the Stresses which Occur in Arc-Welded Structures. R. Sarazin. (Bulletin de la Société des Ingénieurs Soudeurs, 1939, vol. 10, Feb.–Mar., pp. 3375–3399). The author describes how he measured the contraction and bending of steel plates caused by the deposition of a bead of weld metal down the centre of the plates by the electric welding process. The plate was marked to a predetermined plan before welding, the distances between the marks being carefully recorded. After welding the change in distance between the points was measured with great accuracy. From the results obtained he makes recommendations regarding welding procedure with the object of reducing the residual stresses to a minimum.

MACHINING

Metal Cutting. M. F. Judkins. (Mechanical Engineering, 1939, vol. 61, May, pp. 349–355, 378). The author considers the theory and practice of cutting metal dealing chiefly with single-point turning as in a lathe. His study includes the nature and magnitude of the cutting forces, chip formation and removal, the definition, control and measurement of machinability, the selection of materials and tool design.

Relative Machinability of Steels. A. Kullman. (Iron Age, 1939, vol. 143, Feb. 9, pp. 29–32). The author discusses the results of a number of machining tests carried out on tools of American high-speed steels (S.A.E. 1112, X-1335 and 4145) which demonstrated the effect of the alloying elements, heat treatment and grain size upon their life.

Cutting Tools for Cast Iron. H. H. Beeny. (Institute of British Foundrymen (International Foundry Congress), London, June, 1939, Preprint No. 671). The paper is concerned with depicting the machining characteristics of cast iron, so as to determine which is the most suitable tool material. Grey cast iron forms a powdery swarf, whereas ductile metals give a continuous chip. The type and strength of the chip control the severity of the heating, abrasion and stress, which are the influences always tending to destroy the tool. Cutting stresses are not high with cast iron, but the metal is strongly abrasive due to its combined carbon content, to skin conditions, and to the chilled spots and sand inclusions which are sometimes present. Cutting fluids are rarely used and, as a consequence, there also tends to be considerable heating. The machinability of the metal itself is controlled almost entirely by the combined carbon content and the tensile strength; when both are low the most rapid metal removal is obtainable. Sintered tungsten-carbide tools possess superlative hardness and resistance to abrasion and heat. At 600° C. these tools are actually much harder than high-speed steels or Stellite in the cold condition and, as one would expect, they are eminently successful on cast iron. Since the advent of carbide cutting materials, machine tools have been built possessing great static and dynamic stability with increased spindle speeds, ample driving power, improved lubrication systems and harder component materials, so that they are able to withstand the gruelling conditions of high-speed cutting while giving the maximum speed and economy in production. By varying the texture of the tungsten carbide powder and the amount of cobalt, different grades of cutting tip are produced so that extremely hard white iron castings or ordinary grey metal may be

machined under the most suitable conditions. With carbide tools cast iron can be removed at three times the speed previously attainable, while scale, sand and chilled spots have a less detrimental influence; stronger and harder irons can be dealt with efficiently.

Lead-Bearing Steels. (Iron and Steel, 1939, vol. 12, Apr., pp. 392–393; May, pp. 441–443). **Rapid Machining Steel—*G.K.N.* Ledloy.** (Iron and Coal Trades Review, 1939, vol. 138, Mar. 10, p. 456: Engineering, 1939, vol. 147, Mar. 31, p. 381: Machinery, 1939, vol. 54, May 11, pp. 172–173). Some particulars are given of a new steel alloy known as *G.K.N.* Ledloy containing about 0·20% of lead which has just been put on the market. It is stated that the lead is homogeneously distributed as finely divided submicroscopic particles. The results of tests show that the mechanical properties are unaffected by the lead addition whilst the machining properties of Ledloy are very superior to those of mild steel, the improvement being as much as 60%. This new alloy is also just as responsive to case-hardening and heat treatment as mild steel.

CLEANING AND PICKLING OF METALS

(Continued from p. 28 A)

Iron and Steel Descaled and Structural Steel Cleaned and Dehydrated by Oxy-Acetylene Process. J. G. Magrath. (Iron Age, 1939, vol. 143, Apr. 20, pp. 34–39). After describing the composition and nature of scale on steel, the author describes in detail the equipment and technique employed for removing scale from steel billets by the oxy-acetylene flame. Multi-jet burners which can be adjusted to suit different contours of material are used. For cleaning and removing moisture trapped by scale on structural steel prior to painting, the flame is passed rapidly over the surface, the temperature being sufficiently high to turn the moisture into steam which assists in cracking off the scale as it escapes.

Pickling Process. (Steel, 1939, vol. 104, May 22, pp. 58–60). A brief description is given of a pickling plant at the works of the Chicago Bridge and Iron Co. This consists of three tanks, the first containing warm dilute sulphuric acid, the second warm washing water and the third phosphoric acid solution to which iron phosphate has been added. The plant is used mainly for cleaning large plates for tanks. After removal from the third tank the plates are painted while still hot with a red lead and graphite paint.

Practical Aspects of Pickling. P. Dickens. (Metal Treatment, 1939, vol. 5, Spring Issue, pp. 37–39, 48). An abridged English translation of a comprehensive article on the pickling of steel. This paper appeared in Stahl und Eisen, 1938, vol. 58, Nov. 24, pp. 1343–1346. (*See* Journ. I. and S.I., 1939, No. I., p. 168 A).

Electrolytic Cleaning, with Particular Reference to the Pickling of Metal Components. W. Machu. (Korrosion und Metallschutz, 1939, vol. 15, Apr., pp. 105–122). After touching briefly on the disadvantages of mechanical and chemical processes for the descaling and pickling of metals, the author discusses and compares several electrolytic methods of pickling, with numerous references to the literature.

Electrolytic Pickling of Strip Steel. H. W. Neblett. (Iron and Steel Engineer, 1939, vol. 16, Apr., pp. 12–16). The author describes the development, plant and method of operation employed at the Inland Steel Company's works for pickling steel strip. The process is a continuous one, and the plant comprises four acid baths, each about 60 ft. long, in series. Electrolytic equipment is fitted to the second and third baths, the first acting as a conditioning tank in which the acid penetrates the scale, and the fourth as a cleaning tank.

Waste Pickle Liquors. C. L. Knowles. (Steel, 1939, vol. 104, May 15, pp. 54–56). The author gives a brief description of a plant for neutralising waste liquor from pickling installations. Limestone is the material used and this is purchased in bulk in pieces of about $\frac{3}{8}$ in. It is fed from the storage hopper to a cylindrical mill in which it is wet-ground either in water or in wash liquors. The pickle liquor and wash waters are collected in an equalising tank and pumped with the ground limestone to three turbo-mixers operating in series. A coarse gypsum and ferric hydroxide precipitate is produced. The slurry is further conditioned by mechanical flocculation before it is clarified in the Dorr thickener. The effluent is perfectly clear, has a *p*H value over 6, carries in solution only a trace of calcium sulphate and is not harmful to human or fish life. The unit described can treat 18,000 gal. of 1·5% sulphuric acid, 10% iron sulphate liquor and ten times this quantity of wash water per day.

Treatment of Pickling Wastes. N. J. Ranney. (Iron Age, 1939, vol. 143, Apr. 20, pp. 24–27). The author describes the process of neutralising waste pickling liquor with milk of lime and making a building material called "Ferron" from the precipitate. The process was described in Iron and Steel Engineer, 1939, vol. 16, Jan., pp. 52–57. (*See* Journ. I. and S.I., 1939, No. I., p. 289 A).

The Handling of Waste Acids. (Wire Industry, 1939, vol. 6, Feb., pp. 119–120). It is pointed out that vitrified pipes and chemical stoneware pipes used for conveying spent pickle liquor are liable to crack when subjected to rapid changes of temperature, and have little mechanical strength. To overcome these disadvantages, rubber-lined steel, bonded by the "Vulcalock" process, "Triflex" acid-proof rubber linings and "Flexlock" rubber pipe-joints are now used. Some installations using these materials are described in this article.

Methods of Neutralising and Recovering Acid from Spent Pickle Liquor. C. G. Carlsson. (Jernkontorets Annaler, 1938, vol. 122, No. 12, pp. 647–655). (In Swedish). The author reviews the literature on some processes for rendering spent pickle liquor unharmful and others by which sulphuric acid and iron oxide may be recovered from spent liquor. It has been found that of the many processes tried only two or three have been economic, and these require large plants. A bibliography of 84 references is appended.

COATING OF METALS

(Continued from pp. 29 A–31 A)

The Bonderizing of Automobile Bodies. H. M. Sutherland. (Industrial Heating, 1939, vol. 6, May, pp. 438–444, 468). The author describes the furnace equipment at an automobile assembly plant in California which is used for bonderising assembled automobile bodies. The welded body enters the first line of ovens which is 150 ft. long by 11 ft. wide by 9 ft. 3 in. high. This is divided into six compartments with openings from one to the other just large enough for the body to pass through. In the first compartment a powerful alkali spray removes all oil and grease; the second and third are rinsing chambers; the bonderising or spraying with phosphate solution takes place in the fourth compartment; the fifth is another rinsing chamber and in the sixth a spray of chromic acid neutralises the bonderising solution. The body passes from these ovens to a drying oven after which the priming coat of paint is sprayed on. Then follow a series of drying and painting operations. The author includes in his description data concerning the burners, gas consumption, water consumption, temperatures and pressures used in the operation of this plant.

Tinning Plant of Latest Design Installed at Ebbw Vale. (Tin and Its Uses, 1939, Apr., pp. 9–12). A description is given of the automatic tinning plant recently installed at the Ebbw Vale Works of Richard Thomas and Co., Ltd. This consist of ten fully automatic lines, each line comprising a Poole feeder, a Davis feeder, a welded steel pot for melting tin, a Head Wrightson Aetna-Standard tinning machine, a catcher, a wet washer, a dry cleaner, and an automatic piler.

Electro-Tinning. S. Baier. (International Tin Research and Development Council, 1939, Publication No. 92). After enumerating the advantages of tinning by electro-deposition, the author describes the equipment, plating solution and technique employed using three different baths, *viz.*, the stannate bath, the stannous-chloride/caustic potash bath and the acid bath. In conclusion he describes some analytical methods of control and some miscellaneous methods of tinning.

Tin on Tinplate with a Note on Greyness. M. L. Hughes. (Swansea Technical College Metallurgical Society, Mar. 18, 1939). In the first part of his paper the author describes and discusses the process of tinning steel sheet, paying particular attention to stripping and titration methods of evaluating the coating, determining variations in thickness of a coating, and to the effect of porosity on the rate

of corrosion. In the second part, he records the observations made and experiments carried out which led to the conclusion that an important cause, if not the major cause, of greyness, is the occurrence of copper deposition on the sheets during pickling.

Some Considerations Effecting the Manufacture of Steel Sheets for Vitreous Enamelling. J. S. Walton. (Swansea Technical College Metallurgical Society, Presidential Address, Nov. 19, 1938). The author reviews vitreous enamelling practice and discusses factors liable to cause trouble. In his opinion steel of very low carbon content is desirable which should be cast in ingots of the rimming type to ensure the maximum freedom from carbon at the sheet/enamel interface. The steel should contain almost no silicon and be low in sulphur and phosphorus. Maximum resistance to warpage and sagging may necessitate the reduction of the carbon and manganese contents still further until the metal attains the quality known as " open-hearth iron."

Sag-Resisting Properties of Enamelling Iron. F. R. Porter. (Journal of the American Ceramic Society, 1939, vol. 22, June, pp. 176–179). The author gives an account of tests made on specimens of iron and mild steel strip $12 \times 2 \times 0{\cdot}0375$ in. containing carbon 0·03% and 0·10% respectively, in order to determine the amount of sag which occurs on heating. He found that the temperature, the thickness of the strip and the duration of the heating are the factors affecting the amount of sag, and that the mild steel sagged much more than the iron. He concludes from the results that the use of enamel ground coats which mature at temperatures below the normal range (1580–1600° F.) would reduce the amount of sagging and warping which occurs in the manufacture of enamelled sheet metal articles.

Cast Iron for Enamelling. K. Emmel. (Giesserei, 1939, vol. 26, May 31, pp. 285–287). The author describes some experiments with specially prepared specimens of cast iron which showed that enamel adhered well to those specimens with a ferritic structure and badly to those with a pearlitic structure, irrespective of the graphite content and the size of the graphite particles. By another series of tests he ascertained that the amount of creep of cast iron had practically no effect upon its enamellability; in fact the results he obtained rather indicated that the iron with the least amount of creep was the most difficult to enamel.

Foundry and Enamel Practice as Applied to Cast Iron. G. M. Logan. (Institute of British Foundrymen and Institute of Vitreous Enamellers: Foundry Trade Journal, 1939, vol. 60, May 4, pp. 368–370; June 1, pp. 447–450). The author explains the main principles involved in the production of castings which are to be porcelain-enamelled. He discusses in turn the effect of the composition of the pig iron and scrap, the kind of coke, the proportion of limestone, the working of the cupola, the quality of the moulding sand, and shot- and sand-blasting. In the concluding part he discusses the

composition of enamel suitable for specific purposes and the factors which control the finish and durability of the coating. For the wet process of enamelling the important factors are: suitable metal composition and good melting practice; a good smooth surface; thorough shot-blasting and correct firing temperature. On the other hand in dry-process enamelling the shot-blasting does not require to be so thorough and much more skill is required by the enamellers.

The Importance of Cellulose Derivatives in Painting Technique with Special Reference to General Corrosion Problems. G. Schultze. (Korrosion und Metallschutz, 1939, vol. 15, June, pp. 191–195). The author discusses the properties of protective coatings made from cellulose derivatives, and shows that cellulose products have now been developed which can be used with oil-base binding media.

Zinc-Dust Paints for Improved Maintenance of Metal Surfaces. (Steel, 1939, vol. 104, May 1, pp. 42–43, 78). The properties and uses of paints containing metallic zinc powder mixed with a grey pigment are described. It has good adherence and spreading properties, one gallon covering 800 sq. ft., and it makes a good first coat on which aluminium paint may be applied.

Graphite as an Anti-Corrosive Pigment. A. H. Stuart. (Paint, 1939, vol. 9, Apr., pp. 115–116). The author considers reasons for and against the use of graphite as a pigment in paints to protect iron and steel. He describes experiments which show that under certain conditions the corrosion of iron in water will be increased by the presence of graphite, and explains why these conditions do not arise if the graphite particles are of colloidal dimensions. He describes further experiments which support his contention that pure colloidal graphite possesses very valuable properties as an anti-corrosive pigment.

Liquid Life Savers. D. L. Wright and H. D. Kolb. (Steel, 1939, vol. 104, Apr. 24, pp. 48–50). The authors give some particulars of a series of coating compounds and solutions known as "Rust-Ban." These are applied to steel by spraying, dipping or swabbing and are marketed in four general types (*a*) non-drying which are easily removed by a petroleum solvent, (*b*) fluid, (*c*) semi-fluid, and (*d*) solid.

PROPERTIES AND TESTS

(Continued from pp. 98 A–105 A)

New Researches in Steel Metallurgy. W. H. Hatfield. (Royal Institution, Mar. 17, 1939). The author shows that research in steel metallurgy is directed in the main to three principal aspects: (*a*) Elucidation and improvement of the processes of steel manufacture and manipulation, (*b*) the investigation of the properties of steel under variable conditions approximating to those of service, and (*c*) the exploration of the influence of added elements and of the effect of heat treatment in advantageously modifying the properties of steel. The author discusses some of the results which have been obtained in these directions. In investigating creep properties the usefulness of a short-time test was obvious and he describes a three-day test which has been developed and is being used on an extensive scale in the testing of many alloy steels. In this test the applied stress produces deformation not exceeding 0·5% of the gauge length in the first 24 hr., but during the next 48 hr. no further change in dimensions takes place within the accuracy of measurement, which is to 0·0004 in. On a gauge length of 2 in. this is approximately equivalent to one-millionth of an inch per in. per hr. The maximum stress not producing a deformation in excess of that so postulated has been named the "time yield." The determination of the "time yield" enables many steels to be compared as to behaviour at different temperatures.

Tension Tests of Large Riveted Joints. R. E. Davis, G. B. Woodruff and H. E. Davis. (Proceedings of the American Society of Civil Engineers, 1939, vol. 65, May, pp. 805–857). The authors describe an extensive series of tests on large riveted joints in which the effect of variations in length, type of joint, quality of steel, and in the pitch and position of the rivets were studied.

The Behaviour of Metallic Materials in the Range of Small Deformation. F. Körber. (Stahl und Eisen, 1939, vol. 59, May 25, pp. 618–626). The author considers the effects of small deformations on the structure of steel, distinguishing between deformation caused by static and dynamic stresses. He shows that in the range of small deformation local changes of structure take place which are not revealed by X-ray analysis and is of the opinion that, as long as it remains impossible to distinguish by a direct method between the factors which tend to favour fracture and those which tend to prevent it, the question can only be studied by making deductions from the results of fatigue tests.

Fatigue. F. A. Fox. (Machinery, 1939, vol. 54, June 1, pp. 265–268). The author studies the theory of fatigue, the mechanism

of fatigue failure and corrosion fatigue. He explains the "S-N" curve in which the stress is plotted against the number of cycles of stress in a fatigue test, and concludes with some recommendations on the design of fatigue-resisting parts.

Testing Machines for Determining the Fatigue Strength of Machinery Parts. E. Erlinger. (Archiv für das Eisenhüttenwesen, 1939, vol. 12, June, pp. 613–621). The author reviews three kinds of fatigue testing, namely: testing prepared specimens in the Wöhler machine, testing specimens under increasing load until fracture, and making comparative tests of finished machinery parts. He discusses the principles and technique of vibratory methods of testing and distinguishes between testing installations for producing low, medium and high frequency oscillations. He describes in detail a number of testing machines.

The Behaviour of Steel in Push-Pull Fatigue Tests at 500° C. M. Hempel and F. Ardelt. (Archiv für das Eisenhüttenwesen, 1939, vol. 12, May, pp. 553–562). The authors study the behaviour of an unalloyed, a molybdenum and a chromium-nickel-tungsten steel at 500° C. when submitted to alternating push-pull stresses of different mean values, and describe the apparatus used. This apparatus included an automatic device for recording the elongation with such accuracy that the recorded rate of elongation over a period of 10 hr. was correct within $\pm 0{\cdot}5 \times 10^{-4}\%$ per hr. Their conclusions are as follows: (1) Under alternating stresses at raised temperatures elongation took place, the rate of which was high at first and decreased as the test proceeded; (2) the shape of the time-elongation curve depends upon the mean stress and the maximum tensile stress. It is noteworthy that when the mean stress is nought some elongation occurs; (3) the high-temperature fatigue strength cannot be evaluated without reference to the time-elongation curve; and (4) the amount of elongation, the creep strength, the permanent elongation produced by alternating stresses and the rate of elongation must all be taken into account when ascertaining the limits of the high-temperature fatigue-strength curves.

18–8 : Effect of Grain Size on Fatigue Strength. H. Habart and R. H. Caughey. (Metal Progress, 1939, vol. 35, May, pp. 469–470). The authors report on an investigation of two specimens of steel both having the following composition: Carbon 0·07%, manganese 0·46%, phosphorus 0·007%, sulphur 0·009%, silicon 0·55%, nickel 8·62% and chromium 18·80%. These were subjected to special heat treatments so as to produce a wholly austenitic structure with the difference that a coarse grain of 0 to 1 (grain size of the American Society for Testing Materials) was produced in one specimen and a fine grain of 5 to 7 in the other. Tensile, hardness and fatigue tests were then carried out, and their results compared. They found that the fine-grained steel possessed lower ductility, higher tensile and ultimate strength and greater hardness than the coarse-grained steel. The fatigue strength of the former (measured

in the rotating beam machine) was about 15% higher than that of the latter.

The Fatigue Strength of Hard-Chromium-Plated Parts. H. Wiegand and R. Scheinost. (Zeitschrift des Vereines deutscher Ingenieure, 1939, vol. 83, May 27, pp. 655–659). The authors describe an investigation of three kinds of steel with the following contents: (*a*) Carbon 0·46%, chromium 1·60%; (*b*) carbon 0·29%, chromium 2·49%, nickel 0·5%, vanadium 0·20%; and (*c*) a high tensile steel with 0·44% of carbon. The specimens were hard-chromium plated and subjected to tensile, notched-bar impact and fatigue tests. They found that the plating process had no appreciable deleterious effect on the tensile and impact strength, but the fatigue strength was markedly lowered, and they considered that chromium plated steel should not be used for highly stressed parts in engines where the operating temperature is 100° C. or higher.

Here is a Method of Testing the Hardness of Thin Sheets or Foils. (Sheet Metal Industries, 1939, vol. 13, May, pp. 637–638). A description is given of the Salford hardness tester which is designed for measuring the hardness of metal sheets or foils of the order of 0·02–0·03 mm. in thickness. In this machine a load is applied to a steel ball $\frac{1}{16}$ in. in dia. through a spindle and the movement of the latter causes a movement of an iron core between two electro-magnets which are parts of a Wheatstone bridge. The bridge system becomes unbalanced and this is indicated by the needle of a galvanometer in the circuit which moves over a scale calibrated both in millimetres and in the Rockwell hardness numbers. The accuracy of the readings obtained varies between 2 and 5 Rockwell numbers.

The Various Brinell Hardnesses of Cast Iron and Its Relation to the Standardised Test Conditions and the Kind of Iron Tested. H. Reininger. (Giesserei, 1939, vol. 26, May 5, pp. 216–223; May 19, pp. 242–251). The author investigated the causes of the inconsistency of the results of Brinell hardness tests on cast iron when carried out under the conditions specified in the German Engineering Standards. The results which he compared were obtained with (*a*) a ball 10 mm. in dia. with a load of 3000 kg. and (*b*) a ball 5 mm. in dia. with a load of 750 kg. He found that in general the hardness indicated under conditions (*b*) was lower than that indicated under conditions (*a*), and that this was due mainly to the distribution and shape of the graphite particles. The investigation led the author to the conclusion that the Rockwell, Shore and Vickers methods of testing, which use a medium smaller than the ball in the Brinell machine, do not give such reliable results as the Brinell method.

Relation between the Rockwell "C" and Diamond Pyramid Hardness Scales. H. Scott and T. H. Gray. (Transactions of the American Society for Metals, 1939, vol. 27, June, pp. 363–377). The authors report on an investigation of the causes of inconsistencies which are apparent in published data on the results of Rockwell "C"

and Vickers diamond-pyramid hardness tests. The authors tested steel blocks of different analyses, quenched and tempered to various degrees of hardness. The results showed that neither the composition nor the heat treatment affected the relation between the values obtained by the two methods. The authors also converted the Rockwell "C" values to Vickers numbers using Petrenko's equations and found considerable discrepancies on comparing their calculated results with the direct values obtained with the Vickers machine. They attributed these differences to the elastic recovery of the specimens in the Vickers machine. They calculated the amount of elastic recovery from observations of the diameters of impressions made in the Rockwell machine and found this to be relatively large, amounting to 15–20% of the depth of the impression.

Experiments with Nickel-Chromium Wear-Resisting Cast-Iron Alloys. J. E. Hurst. (Metallurgia, 1939, vol. 20, May, pp. 1–4). The author describes a number of service tests on liner plates of a rotary ball mill used for crushing chilled white iron. The materials tested in this and other ways consisted of iron-nickel-chromium alloys of chemical compositions within the following limits: total carbon 2·0–4·0%, silicon 0·15–1·5%, nickel 3·0–7·0% and chromium 0·0–2·5% and they included those sold under such trade names as Ni-Hard, Attritard, *BF* 954 and others. He discusses the influence of other elements, in particular manganese, upon the mechanical properties of these alloys. In conclusion he presents a table showing the effect of low-temperature heat treatment upon *BF* 954 which shows that this treatment even at 200° C. produces a substantial increase in strength.

The Magnetisation of High-Coercivity Iron-Nickel-Aluminium Alloys by the Method of Superimposing an Alternating Magnetic Field on a Constant Magnetic Field. A. Kuznetsov. (Stal, 1938, No. 10, pp. 47–48). (In Russian). The author gives a short description of the apparatus used for magnetising high-coercivity iron-nickel-aluminium alloys and discusses the results obtained with it. He found that for one and the same amplitude of the alternating field the maximum coercive force was obtained with the constant field less than the value of the residual inductance. The ratio of the constant field to the amplitude of the superimposed alternating field, which is necessary in order to obtain maximum residual inductance and consequently also maximum coercivity, is shown diagrammatically.

Improving the Magnetic Properties of Transformer Steel by Annealing in a Magnetic Field. O. Grekhov and P. Glushkova. (Stal, 1938, No. 10, pp. 40–46). (In Russian). Extensive experimental data as to the effect of annealing temperature, annealing time, rate of cooling and subsequent ageing on the properties of transformer steel annealed in a magnetic field are given. By annealing ordinary transformer-steel sheet 0·5 mm. thick in a magnetic field intensity of 20 oersted for 2 hr. at 720° C., specimens 65 × 600 mm. had their permeability increased up to 16,000 μ, as compared

with 5000 to 6000 μ for the original material. Watt losses were reduced by 20–30%, as compared with the original material and as compared with a reduction of 11–15% obtained by ordinary annealing. The best results are obtained on annealing transformer steel which had been subjected to a preliminary refining annealing treatment at 1100° C. for 6 hr. in a hydrogen atmosphere.

Magnetic Method of Testing Grey Cast Iron. Ya. P. Abramson, I. Ya. Levshuk and V. I. Nikolin. (Zavodskaya Laboratoriya, 1939, No. 2, pp. 178–182). (In Russian). A magnetic induction method was developed and tried out for the routine testing of piston rings. The apparatus consisted of a pair of identical magnetising coils and a pair of measuring coils. The magnetising coils were supplied with current through a variable resistance direct from the 220 v., A.C. mains whilst the measuring coils were connected through a copper oxide rectifier to a shunted galvanometer. A piston ring with maximum magnetic permeability was used as a standard and the correlation between the readings of the galvanometer and the microstructural characteristics of the piston rings placed in the second magnetising coil was investigated. Typical microstructures are reproduced. The magnetic induction method was found to be suitable for the detection of cementite, either in separate areas or in the form of a network. The method can also be used to classify pistons on the basis of the amount and form of graphite present. It cannot be used, however, to distinguish rings with a ledeburite matrix from rings containing graphite. No definite connection between the readings of the instrument and the wear resistance and mechanical properties of the rings could be established.

The Behaviour of Steels at High Temperatures. C. A. Duckwitz. (Berg- und Hüttenmännische Monatshefte der Montanistischen Hochschule in Leoben, 1939, vol. 87, May, pp. 97–105). The author discusses a number of methods of determining the strength of steel at high temperatures and classifies them in six groups as follows: (1) Determination of the rate of elongation during a given time at constant load and temperature; (2) determination of a permanent elongation after a definite time at constant load and temperature; (3) determination of a load at constant temperature, elongation and time; (4) determination of a temperature limit at constant load and elongation; (5) prolonged tensile tests; and (6) a special method of testing tubes developed by the Forschungsinstitut der Mannesmannröhren-Werke. He shows how the values obtained by these methods depend upon the recrystallisation which occurs during deformation. He describes the method of testing tubes referred to in (6). For this method the specimens of tube are specially prepared in a machine like a lathe in which, by means of a series of rollers, a number of corrugations are formed on the outer surface of the tube. The specimen is then heated in a furnace to 650° C. A flexible tube is connected to it into which nitrogen is admitted at gradually increasing pressure until fracture occurs. Automatic

pressure and temperature recording instruments are connected to the apparatus. As an example of the application of the results which can be obtained by this method of testing the author states that on testing one plain and one corrugated tube of the same inside diameter with the outside diameter of the former equal to the diameter at the base of the corrugations on the latter, it was found that: (1) the latter weighed 50% more than the former; (2) the surface area of the latter was 70% greater than that of the former; (3) the corrugations improved the thermal conductivity by 35–40% and the strength by 80–85%.

Creep Strength Tests while Recording Time-Stress Curves. K. Wellinger. (Archiv für das Eisenhüttenwesen, 1939, vol. 12, May, pp. 543–550). The author describes a method of creep testing which was developed at the Stuttgart Material Testing Laboratory. This was a method in which the first two of the three variables temperature, strain and stress were kept constant when testing different specimens and the different stresses required to produce the same strain in the different specimens were measured and compared. A 50-ton tensile testing machine was used and a recording device controlled by a very delicate vacuum-enclosed switch enabled stress-time curves to be obtained as the tests proceeded. He presents and discusses the results obtained with this machine on a number of alloy steels.

The Effect of Nitrogen on Chromium-Bearing Alloys. A. M. Samarin, M. L. Korolev and I. V. Paisov. (Metallurg, 1938, No. 11, pp. 80–83). (In Russian). Investigations were made on the effect of nitrogen introduced into the bath during the melting of high-chromium iron alloys (28% of chromium) and Fechral alloy (15 or 20% of chromium and 3·4–5% of aluminium). The nitrogen was introduced into the melts by the addition of high-nitrogen-bearing ferro-chromium or chromium, while in one case ammonia was blown through the molten alloy. The presence of nitrogen in these alloys was found to prevent a columnar zone forming in the ingot and to favour the formation of a fine-grained structure. The higher the nitrogen content in the iron-chromium alloys, the finer was the ferrite grain, the higher were the tensile strength, proof stress and impact strength and the lower were the elongation and reduction in area.

Effect of Aluminium on the Deformation Properties of Unalloyed, Medium Carbon, Cast Steel. C. E. Sims and F. B. Dahle. (Stahl und Eisen, 1939, vol. 59, June 15, pp. 711–713). An abridged translation into German of an article published in Transactions of the American Foundrymen's Association, 1938, vol. 46, pp. 65–103. (*See* Journ. I. and S.I., 1938, No. II., p. 390 A).

The Effect of Silicon in Structural Steel. H. Wilhelm and J. Reschka. (Archiv für das Eisenhüttenwesen, 1939, vol. 12, June, pp. 607–612). Using a dilatometer the authors investigated the effect of the silicon content on the transformation points and physical

properties of a number of steels containing carbon 0·17–0·5%, silicon 0·01–1·3%, manganese 0·3–1·2% and copper 0·2%. They also studied the optimum annealing temperature and the effect of silicon on the welding properties. They found that only the carbon and manganese contents affected the A_3 point of steels containing up to 1·3% of silicon. The effect of the silicon is noticeable however in the heating curve at a point Ac_3' which lies above Ac_3, and an examination of the structure revealed that the transformation to γ-iron is only complete when Ac_3' is reached. It was also found that silicon raised the temperature at which the formation of γ-iron was complete; 1% of that element raised the temperature by 120° C. as compared with the Ac_3 point determined dilatometrically. Steels annealed at the Ac_3' temperature possessed properties complying with the requirements of structural steel. Tests made with steels containing up to 1·2% of silicon showed they had satisfactory welding properties provided that electrodes of suitable composition were used.

Specific Effect of Alloy Additions in Steelmaking. A. B. Kinzel. (Canadian Metals and Metallurgical Industries, 1939, vol. 2, Apr., pp. 86–88). The author classifies the alloying elements added to steel into three groups. In the first group are those elements which readily form carbides and promote the retention of the ferrite; such elements are: chromium, vanadium, molybdenum, tungsten and niobium. The second group consists of oxidising elements which in certain cases tend to suppress the transformation of ferrite to austenite, these include silicon, aluminium, calcium and zirconium. The third group contains the elements which promote the formation of austenite from ferrite and tend to retain the austenite once it is formed; such austenite promoters are: manganese, nickel, copper, phosphorus and nitrogen. The author then discusses additional effects, such as changes in grain size, hardness, corrosion resistance, weldability and strength properties, which some of these elements have upon steel.

The Influence of Composition on the Physical Properties of Grey Irons. R. Schneidewind and R. G. McElwee. (American Foundrymen's Association, May, 1939, Preprint No. 16). The authors discuss the factors affecting the properties of grey iron with particular reference to the influence of carbon, silicon and additions of vanadium, of deoxidising agents and of size of section.

Copper, Aluminium, Silicon Alloys for Addition to Cast Iron. V. H. Schnee and T. E. Barlow. (American Foundrymen's Association, May, 1939, Preprint No. 28). The authors describe their investigation of the effects of adding a complex alloy containing a strengthening element combined with deoxidising elements to molten cast iron in the ladle. Preliminary trials showed that an alloy containing 6% of aluminium, 12% of silicon and 80% of copper was most suitable for a medium-carbon iron melted in an electric furnace. They found that the addition of 1% of this alloy

in the ladle was sufficient to improve markedly the mechanical properties of the iron, the improvement being greater than that produced by the addition of 0·5% of silicon.

Physical Properties of Cast Iron in Heavy Section. E. R. Young, V. A. Crosby and A. J. Herzig. (Transactions of the American Foundrymen's Association, 1938, vol. 46, pp. 891–909). The authors have collected data relating to the physical properties of sixty-eight different plain and alloyed irons cast in test bars 27 in. long and 2 in. in dia. These are presented in tables, by graphs and by micrographs of etched sections. The data demonstrate among other things that irons containing less than 0·20% of molybdenum have a tensile strength of 5000 lb. per sq. in. greater than that of plain carbon irons, and that this difference is increased to about 14,000 lb. per sq. in. when the molybdenum content exceeds 0·20%.

Trends in the Development of Alloy Steels. E. Houdremont. (Technische Mitteilungen Krupp, Technische Berichte, 1939, vol. 7, May, pp. 45–60). The author discusses how both laboratory tests and experience gained in service have influenced the development of structural and alloy steels. This article appeared previously in Stahl und Eisen, 1939, vol. 59, Jan. 5, pp. 1–8; Jan. 12, pp. 33–39. (*See* Journ. I. and S.I., 1939, No. I., p. 238 A).

Alloy Steels in the Mining Industry. G. K. Herzog. (Transactions of the Canadian Institute of Mining and Metallurgy, 1938, vol. 41, pp. 246–260). The author reviews the advantages of certain alloy steels, particularly those more recently developed, and indicates by specific examples the type of mining equipment for which they are best adapted.

Properties of Some Copper-Bearing Cast Steels. C. T. Greenidge and C. H. Lorig. (American Foundrymen's Association, May, 1939, Preprint No. 29). The authors report the results of an investigation of the effects of additions of up to 2·40% of copper on the properties of cast steel. The steels tested included specimens with additions of copper only and low-alloy steels containing one or more of the following elements: vanadium, titanium, aluminium, molybdenum, niobium, zirconium, chromium, silicon and manganese, the last two in higher than normal percentages. The authors present tables of the properties of the cast steels in the fully annealed, the normalised, the normalised and tempered, and the quenched and tempered state. They found that the addition of more than 0·50% of copper markedly increased the tensile and yield strengths of fully annealed, of normalised, and of quenched and tempered cast steels and only slightly lowered the ductility and resistance to impact. As the addition of copper increases the yield strength more rapidly than the tensile strength, the copper-bearing steels have high yield ratios. Several combinations of copper with one of the elements mentioned above are useful in the production of high-strength cast steels, and the authors pay particular attention to

the properties of copper-manganese-titanium and copper-chromium steels containing either aluminium or titanium.

The Effect of the Austenite Grain Size in Steel on the Properties of Parts Manufactured from it. I. S. Kozlovskiy and M. A. Leonov. (Vestnik Metallopromyshlennosti, 1939, No. 2, pp. 56–73). (In Russian). Using low alloy steels of essentially the same composition, but with a McQuaid–Ehn grain size of not more than 2–4 on the one hand and not less than 6–7 on the other, a number of lorry parts subject to high stresses such as connecting rods, gearbox pinions, &c., were manufactured. The authors present test data regarding the behaviour of the different grain size steels during forging, heat treatment and machining, and the effect of grain size on the properties of the finished parts. Both the manufacturing processes and the final properties were affected by the grain size and the tests carried out enabled optimum values of the grain size to be determined. Although previous work had not shown any difference in the life of tools when machining normalised fine and coarse grained steel, the present investigations confirmed that fine grained steels after normalising or annealing at 870–900° C. gave a poorer surface finish. This could, however, be improved by machining after the grain size had been coarsened by annealing or normalising at 970–1000° C.

Grain Size Number and the Mechanical Properties of Axle Steel. V. Makhov. (Stal, 1938, No. 10, pp. 48–53). (In Russian). After summarising the features of the process of manufacturing axles from steel containing carbon 0·27–0·37% and manganese 0·46–0·90%, the author presents an extensive amount of experimental data, mainly in graphical form, in order to illustrate the connection between the grain size and the properties of the finished locomotive axles. He finds that the static tensile strength depends only to a slight extent on grain size. Elongation and reduction in area in tension and particularly the proof stress increase somewhat with increasing grain size number. The impact strength increases appreciably as the grain size number increases. The grain size also affects the impact strength at low temperatures, the existence of fine grains lowering the temperature at which the steel becomes brittle. The impact strength of fine-grained steel depends to a less extent on the ultimate tensile strength than does that of coarse grained steel. The conclusion is that a steel with grain size No. 6 should be used for axles.

Valve and Valve Seat Technique for Automobile Engines. F. R. Banks. (Mond Nickel Co., Ltd., Bureau of Information on Nickel, 1939, No. A35). After enumerating the requirements of exhaust valves for internal combustion engines, the author discusses in detail the design of valves, valve seats and exhaust gas ports, and suitable steels for valves. Silicon-chromium steels are generally adopted, and in England the one commonly used is " Silcrome No. 1," whereas in America two new steels have been developed known

as Silcrome " XCR " and " XB." The analyses of these steels and of the austenitic steel specified by the British Air Ministry are given below :

	Silcrome.			Air Ministry Specification.
	No. 1. %	" XCR." %	" XB." %	D.T.D. 49b. %
Carbon . . .	0·40–0·50	0·40–0·50	0·60–0·86	0·35–0·45
Manganese . .	0·40–0·60	1·00 max.	0·20–0·60	0·50–1·00
Silicon . . .	3·50–4·25	1·00 max.	1·25–2·75	1·00–1·75
Chromium . .	7·50–8·50	23·25–24·25	19·00–23·00	12·50–14·50
Nickel . . .	0·50	4·50–5·00	1·00–2·00	12·50–14·50
Molybdenum . .	...	2·50–3·00	...	...
Phosphorus . .	0·03 max.	0·035 max.	...	0·03 max.
Sulphur . . .	0·03 max.	0·035 max.	...	0·03 max.
Tungsten . .	...	...	...	2·00–3·00

The Iron-Carbon Alloys Examined from the Point of View of Safety. J. Merklen and E. Vallot. (Génie Civil, 1939, vol. 114, May 6, pp. 380–384). The authors discuss the examination of rails and steel in rolling stock by mechanical tests and the use of the microscope, and describe a principle of design which, when applied to wheels and crank webs, would tend to prevent fractures.

New Materials in Steam Generating Plants. H. Harris. (Nickel Bulletin, 1939, vol. 12, May, pp. 102–104). The author describes some of the applications of nickel steel and nickel iron to steam generating plant where their resistance to high-temperature furnace gases has fully justified the additional cost.

Steel for Pneumatic Chisels. G. Livshits. (Stal, 1938, No. 10, pp. 59–60). (In Russian). Comparative tests showed that pneumatic chisels of plain carbon steel containing carbon 0·81%, silicon 0·23% and manganese 0·25%, had a better wear resistance than those of steels with small additions of chromium and tungsten.

ArMaSteel. C. F. Joseph. (Iron Age, 1939, vol. 143, May 25, pp. 27–31). The author discusses the properties and applications of a new American steel used in the automobile industry for either castings or forgings. It contains carbon 2·65–2·75%, silicon 1·25–1·35%, manganese 0·38–0·42%, sulphur 0·15%, and phosphorus 0·05%. The metal is originally cast white, and it is afterwards heat-treated to a point where sufficient carbon is precipitated to produce the desired properties in the material. It is therefore called an " arrested malleabilised " steel or " ArMaSteel."

British Standard Specification for Cold Rolled Mild Steel Strip for General Engineering Purposes. (British Standards Institution No. 847–1939). This specification was prepared under the authority of the Iron and Steel Industry Committee as the result of a request from the Institution of Gas Engineers.

British Standard Specification for Fusion Welded Steel Air Receivers. (British Standards Institution, No. 487, Revised 1939).

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 106 A–109 A)

Examples of the Application of X-Rays in the Steel Foundry. H. von Eckartsberg, H. Juretzek and W. Mantel. (Archiv für das Eisenhüttenwesen, 1939, vol. 12, May, pp. 565–569). The authors discuss the limitations of the application of X-rays for the detection of faults in steel castings and the reasons for these limitations. They show that X-ray films will only reproduce correctly the intensity of the penetrating rays within a certain range, so that the differences in thickness of the parts of the casting appearing on one X-ray photograph must not be so great as to cause differences in penetration outside of the intensity range of the film used. They point out the difficulties which are caused by contrast effects and the occurrence of secondary rays at the edges of the casting, and, as a means of overcoming these, they describe a technique using hard rays, in which the soft rays are absorbed by heavy metal foil before they reach the casting. They conclude by declaring that they believe the use of X-rays for material acceptance tests will remain very limited.

Recent Applications of X-Ray Spectrography to Some Metallurgical Problems. A. Michel. (Chimie et Industrie, 1939, vol. 41, Apr., pp. 627–637). After pointing out some of the limitations of the Debye–Scherrer method of crystal analysis, the author describes the principles and apparatus used in a new method of measuring the lattice parameters of metals and alloys by determining the relative positions of the spectrum lines of a standard salt (such as common salt) and of the substance under examination, using a wide angle between the refracted rays (75–85°). A simple calculation is then made to determine the lattice parameters. The results obtained are accurate within $\pm 0{\cdot}0002$ Å. In conclusion the author gives some examples of the application of this method to the study of solid solutions in alloys.

The Effect of Dimensional Factors on the Quality of X-Ray Radiographs. R. Berthold. (Archiv für das Eisenhüttenwesen, 1939, vol. 12, June, pp. 597–602). The author explains the effects of the various dimensional factors in the apparatus used for making X-ray exposures on the quality of the radiographs produced. The factors are: The area of the anticathode, the distance between it and the area under examination, and the distance between the film and the area being examined. He points out the optimum relationship between these factors and states the requirements of an X-ray tube with an anticathode of adjustable area for the production of high-quality radiographs.

Application of Electron Diffraction to Metallurgical Problems. A. G. Quarell. (Metallurgist, 1939, vol. 12, Apr., pp. 24–27). After describing the construction and principles of the Finch electron diffraction camera, the author discusses some investigations of the surfaces of metals which have been made with this instrument from which it is seen that the development of this technique has reached a stage where it could be more generally applied to the investigation of surface structure problems.

Factors Influencing the Rate of Spheroidisation and Graphitisation in Carbon Steels. C. L. Shapiro. (Industrial Heating, 1939, vol. 143, May, pp. 402–406). The author describes a number of processes of change of structure by which the pearlite in annealed steels changes to spheroidised cementite, and he then examines the influence of cold work upon the rate of spheroidisation. He finds that cold work prior to tempering below the critical temperature accelerates the spheroidisation process and that the greater the amount of deformation, the greater is the acceleration. He also finds that cold work prior to normalising slightly increases the rate of spheroidisation, whilst after normalising cold work greatly increases this rate. In conclusion he considers the effect of additions of alloying elements on the rate of formation of graphite and shows that silicon, copper, aluminium and cobalt accelerate graphite formation, whereas the carbide-forming elements chromium, tungsten and vanadium retard it.

The Influence of Undercooling on the Graphite Pattern of Grey Cast Iron. R. Schneidewind and C. D. D'Amico. (American Foundrymen's Association, May, 1939, Preprint No. 5). The authors describe an investigation of the effect of the rate of cooling upon the structure and the size, shape and distribution of the graphite in grey iron. For this purpose they cast wedge-shaped specimens 12½ in. long, 2¼ in. wide, tapering from 2½ in. in thickness to the point of the wedge. Thermocouples were fixed at six points along the length of the wedge and cooling curves were plotted from the results obtained. They also made hardness determinations, took micrographs and studied the transformations by magnetic methods. The authors found that: (1) cast iron can be undercooled as much as 100° F. below the theoretical equilibrium freezing point; (2) within the range 2060–1970° F., the lower the solidification temperature, the finer is the graphite and the greater the tendency to form a eutectic.

An X-Ray Method of Investigating the Effect of Small Amounts of Aluminium and Vanadium on the Recrystallisation of Iron and Steel. V. I. Ivernova. (Zavodskaya Laboratoriya, 1939, No. 2, pp. 187–193). (In Russian). The author studied iron alloys containing 0, 0·2, 0·99 and 4·36% of aluminium and two carbon steels deoxidised with small amounts of aluminium or vanadium after 16% and 30% deformation. In both cases the Debye method was used. He discusses at some length the theory underlying the

X-ray methods and the results obtained. In general he finds that aluminium present in solid solution in the α-iron lattice considerably raises the temperature at which recrystallisation sets in, but does not affect the temperature at which recrystallisation is complete. In the form of alumina, on the other hand, the aluminium lowers the upper temperature somewhat without affecting the temperature at which recrystallisation sets in. Vanadium sesquioxide in the same steel markedly raises the crystallisation temperature. On the basis of Heller and Sachs' recrystallisation theory and the X-ray and metallographic experimental results obtained, the author calculated the number of recrystallisation nuclei formed per unit volume and the linear rate of growth of the recrystallising grains. The number of nuclei is increased by the presence of aluminium or vanadium oxides, which, however, have only a slight effect on the rate of growth of the grains.

Recovery, Recrystallisation and Creep Behaviour of Some Cold-Worked Austenitic Materials. H. Cornelius. (Metallwirtschaft, 1939, vol. 18, May 12, pp. 399–403; May 19, pp. 419–421). The author describes an investigation of the relationship between the recovery of the strength properties and the recrystallisation of cold-worked steels of cubic face-centered structure and their behaviour when subjected to fatigue tests. Tensile tests were also carried out before and after the fatigue tests. Specimens of steel of three different analyses were tested; the first contained carbon 0·16%, nickel 9·1%, chromium 17·6%, tungsten 0·8% and molybdenum 0·1%; the second carbon 0·45%, nickel 30·1%, chromium 27·4% and titanium 1·9%; and the third carbon 0·08%, nickel 40·0% chromium 15·7%, cobalt 20·6% and tungsten 5·9%. The cold-working was effected by elongating the specimens by different amounts in a tensile machine, and after annealing at various temperatures the amount of recovery was determined. The test results are presented by graphs, micrographs and tables. The author's general conclusions were that the effect of fatigue stresses on the static strength properties of the cold-worked specimens was no greater than that produced on specimens which had not been cold-worked, and that the extent of the improvement in fatigue strength which can be obtained by cold-working cannot be predicted but must be separately determined for each material.

Effect of H_2 on Body-Centered–Face-Centered Transition in Iron. C. B. Post, R. E. Lake and W. R. Ham. (Transactions of the American Society for Metals, 1939, vol. 27, June, pp. 530–537). The authors discuss the effect of the presence of hydrogen in solution upon the A_3 point of iron, their conclusions being based on experiments in which hydrogen was passed through iron sheets about $\frac{1}{8}$ in. thick using an apparatus which enabled the pressure of the hydrogen on each side of the sheet to be controlled and readings of the temperature and hysteresis to be taken. Using this apparatus (which is not described) the authors develop techniques by which

the Ac_3 and the Ar_3 points can be determined with great accuracy, and they find that lowering the pressure on the entry side of a relatively pure iron sheet from 74 to 18 cm. of mercury and keeping a pressure of not more than 0·0030 cm. of mercury on the exit side raises the transition point, as measured by the diffusion method, approximately 1° C.

The Transformations in Hypoeutectoid Steels on Heating. A. S. Zav'yalov and Z. N. Krasil'shchikov. (Metallurg, 1938, No. 11, pp. 35–47). (In Russian). The investigation consisted of obtaining dilatometric curves (for different rates of heating) for plain carbon and a number of alloy steels. The study of these curves was in some cases supplemented by hardness measurements and microscopic examination. Subsequent dilatometric measurements were made to investigate the solution of carbides in austenite. The holding at constant temperatures as well as the rate of heating in the critical temperature range may affect the position of the Ac_3 point even more than does the chemical composition of the steel. The Ac_3 and more particularly the Ac_1 points are also affected as regards position by the rate of heating through the subcritical temperatures. Both the critical points also depend to some extent on the degree of dispersion of the structural constituents. The Ac_3 point is, apparently, connected not with the transformation of ferrite into α-iron but with the going into solid solution of "secondary pearlite," *i.e.*, pearlite lower in carbon, formed in regions of the ferrite owing to diffusion into them of carbon from eutectoid regions. In steels containing special carbide-forming elements there occur, in addition to changes at the Ac_1 and Ac_3 points, changes connected with the solution of the carbides. Complete solution of a given carbide may be characterised by a "critical point of solution" which is affected by the rate of heating and the degree of dispersion of the carbide. It is suggested that the solution of carbides is preceded by their dissociation, the products of dissociation then dissolving.

The Structural Transformations in Cast Iron on Annealing. H. Hanemann and A. Schrader. (Archiv für das Eisenhüttenwesen, 1939, vol. 12, June, pp. 603–604). Using the iron-carbon-silicon equilibrium diagram as a basis, the authors study the transformations which occur when cast iron is annealed. They find that the A_1 transformation does not take place at a specific temperature but over a temperature range. In addition to the precipitation of austenite with the separation of cementite or graphite, which is a reversible process, there is also the irreversible transformation from the metastable cementite system to the stable graphite system. An increase in the silicon content raises the temperature of the A_1 transformation, increases the rate of the reactions, and, on cooling, the crystallisation which occurs tends to become stable. When the phosphorus content is increased the transformations tend to become metastable.

Change in the Carbide Phase on Heat Treatment of a Corrosion Resistant High-Carbon Steel Containing Chromium and Molybdenum. I. G. Oreliovich. (Metallurg, 1938, No. 12, pp. 61–67). (In Russian). The steel studied had the following composition: carbon 0·67%, silicon 0·37%, manganese 0·27%, phosphorus 0·004%, sulphur 0·006%, chromium 16·2% and molybdenum 2·06%. Dilatometric analysis showed that the $\alpha \rightarrow \gamma$ transformation and solution of the carbides set in at 805° C. and are complete at about 880° C. On cooling in air an inflection in the curve, indicating the martensite transformation, occurs at 310° C. A study of suitable quenching and tempering temperatures based on the dilatation curves, microscopic analysis and determination of mechanical properties showed that quenching from 1050–1075° C. in oil and tempering at 750–800° C. gave the best results. The microstructure after such a treatment was sorbitic with comparatively large globules of carbide. Having regard to the importance from the point of view of corrosion resistance of the composition and distribution of the carbides, analyses of them after electrolytic separation were carried out in steel which had been quenched from and tempered at different temperatures. The result of these analyses to a considerable extent amplified the results obtained by dilatometric analysis. The solubility of the carbon in the solid solution increased up to 1250° C., being most intense between 950° and 1050° C. A marked drop in solubility occurs at 1250–1300° C. owing to the appearance of δ-iron. On heating quenched steel, decomposition sets in at 500–550° C., but only the maximum at 600° C. is indicated by the dilatometric curve.

Investigation of the Transformation of Austenite at Temperatures Below 0° C. A. P. Gulyaev. (Zavodskaya Laboratoriya, 1939, No. 2, pp. 230–231). (In Russian). The author describes the apparatus used and an experimental magnetic method of studying the transformation of austenite at low temperatures down to that of liquid nitrogen. He reproduces some of the transformation-rate curves which he obtained.

CORROSION OF IRON AND STEEL

(Continued from pp. 110 A–112 A)

The Objects and Organisation of Committee No. IV of the Belgian Association for the Study, Testing and Application of Materials. (Bulletin de la Société Royale Belge des Ingénieurs et des Industriels, 1939, No. 2). In this publication full particulars are given of the administrative and executive sides of the organisation set up in Belgium for the study of the corrosion of metals, as well as of the testing campaign which has been planned.

Appliances for the Experimental Study of the Natural Corrosion of Steels in Every-Day Use. Séguenot. (Chimie et Industrie: Extrait des Journées de la Lutte contre la Corrosion, 1939). The Corrosion Committee of the Office Technique pour l'Utilisation de l'Acier has undertaken the study of the atmospheric corrosion of steel. In this paper the author describes the preparation and composition of the specimens, the methods of fixing them, the tests and the system for recording the results. The article is illustrated with photographs of testing stations which have been set up in various parts of France.

Preliminary Experience with Long-Time Tests of Natural Atmospheric Corrosion. G. Chaudron. (Chimie et Industrie: Extrait des Journées de la Lutte contre la Corrosion, 1939). The author discusses some of the results so far obtained from the long-time corrosion tests organised by the Corrosion Committee of the Office Technique pour l'Utilisation de l'Acier in France. He shows that the mechanical effects of rolling produce films and these in turn form cells producing an e.m.f. which accelerates corrosion to such an extent that the effect of the composition of the steel is completely masked. He presents two series of graphs which demonstrate the effect of the angle at which a specimen is placed and the effect of rain upon the rates of corrosion of specimens exposed to the atmosphere.

Present State of Our Knowledge on the Corrosion and Corrosion Protection of Iron and Steel. F. Eisenstecken. (Stahl und Eisen, 1939, vol. 59, May 4, pp. 537–548). In this review, which includes 180 references to the literature, the author considers first the theory of corrosion, then the influence of chemical composition and of the processes of deformation and welding. He deals next with the corrosion of high-alloy steels and the corrosion caused by various conditions of service such as hot water in boiler plants, by impure water, by hydrogen and sulphuretted hydrogen, the corrosion of plates in the holds of lighters and ships and influence of direct and

high-frequency currents on the rate of corrosion. He devotes the second part of his review to the protection of iron and steel by metallic and non-metallic coatings and concludes with some notes on corrosion testing in the laboratory.

Corrosion and Corrosion Measurements. A. Demski. (Gas- und Wasserfach, 1939, vol. 82, May 20, pp. 341–349). The author compares some of the existing methods of measuring corrosion, and points out the need of a method of studying the increase of corrosion in relation to time. He then describes the development of such a method which is based upon the fact that the electrical conductivity of the products of corrosion is much less than that of the metal itself. He describes the instruments used, evaluates the results obtained and refers to experiments which show how the life of gas mains depends upon the degree of purity of gas carried.

The Thickness of Air-Formed Oxide Films on Iron. W. H. J. Vernon, F. Wormwell and T. J. Nurse. (Journal of the Chemical Society, 1939, Apr., pp. 621–631). The authors estimate the thickness of air-formed oxide films on high-purity iron and on mild steel by making a chemical analysis of films stripped from the underlying metal by treatment in a solution of iodine in anhydrous methyl alcohol in the absence of air. They correlate the data (supplemented in certain cases by determination of total oxygen in the surface film by Sloman's vacuum-fusion method) with gravimetric determinations of oxygen taken up during exposure to air.

Seven Years' Corrosion Tests on Steel Strip in Soil and in the Air. K. Daeves. (Stahl und Eisen, 1939, vol. 59, June 15, pp. 710–711). The author discusses the results of corrosion tests on four kinds of copper-bearing steel in which the losses in weight were determined after seven years' exposure on some specimens buried in a garden and others exposed to the atmosphere in the country. The steels varied in composition between 0·015 and 0·095% of carbon and 0·04 and 0·31% of copper. The results showed that the loss in weight was approximately the same in each case. Actually, for steel containing more than 0·15% of copper, the loss was 100–200 g. per sq. m. of surface per year.

Application of Electrochemical Measurements to Studies of the Corrosion of 18–8 Stainless Steel. R. H. Brown and R. B. Mears. (Transactions of the Faraday Society, 1939, vol. 35, Apr., pp. 467–474). It is known that the presence of ferric ion in a solution promotes the attack on 18/8 stainless steel, and, if the corrosion of stainless steel is electrochemical in nature, the presence of the ferric ion would be expected to increase the intensity of attack by reducing the polarisation of one or both of the electrodes of the local corrosion cells. In this paper the authors describe some experiments undertaken to test this theory. Two specimens of stainless steel were cleaned and coated with wax, one was scratched and the two specimens were immersed in a sodium chloride solution; the open circuit potential of the two specimens was measured and

time-potential curves were drawn. They found that this curve departed from the ideal cathodic curve because some anodic polarisation took place, and as the ferric chloride concentration increased the departure became more pronounced. Ferric chloride has relatively little effect on anodic polarisation. In general the results showed that in solutions containing substantial amounts of ferric chloride, the occurrence of initial corrosion breakdowns on stainless steel cannot be detected by single potential measurements.

Corrosion Resistance and Ageing Capacity of the Chromium-Copper Steel *DS*. E. G. Shumovskiy, K. N. Klimov and K. I. Smyslov. (Metallurg, 1938, No. 11, pp. 94–102). (In Russian). The authors investigated twelve samples of the steel containing chromium 0·4–0·8%, copper 0·25–0·73%, carbon about 0·2% and manganese about 0·7%. They tested the corrosion resistance by six months exposure to the atmosphere and by intermittent immersion in water. They also studied the tendency to age by means of notched-bar impact tests and present some supplementary data on grain size determination of this type of steel. They noted in particular that good resistance to atmospheric corrosion coincided with the presence of the finer grain-size obtained by deoxidation with an aluminium-manganese-silicon alloy. With the exception of a few experimental heats, specimens of *DS* steel tended to age excessively. The definitely fine-grained steels had higher impact strength in the rolled condition and showed the smallest loss in impact strength on ageing.

BOOK NOTICES

(Continued from pp. 119 A–120 A)

IMPERIAL INSTITUTE. MINERAL RESOURCES DEPARTMENT. "*Magnesium, Magnesite and Dolomite.*" By J. LUMSDEN. (Reports on the Mineral Industry of the British Empire and Foreign Countries). 8vo, pp. vi + 126. London, 1939 : The Imperial Institute. (Price 2s. 6d.)

This report not only covers all aspects of the magnesium metal industry and the other industries in which magnesite and dolomite play an important part, but also reviews the world resources of magnesium minerals of economic importance, particularly magnesite. Although special emphasis is laid on Empire deposits, those in foreign countries are by no means neglected. In addition to descriptions of the deposits, chemical analyses and tables of production and trade statistics are included where possible. The commercial manufacture of magnesium metal was for long a matter of great technical difficulty, and Germany was the only manufacturer, but processes developed during the last few years have led to a greatly increased output, the present world production being estimated at about 25,000 tons. Apart from its use in alloys, the most important modern use of magnesium is as a scavenger in metal refining on account of its strong chemical affinity for oxygen and nitrogen. Although magnesite is the chief raw material for the manufacture of magnesium metal it is much more important as a refractory material, especially in steel furnaces. It is widely distributed in nature, though extensive deposits of economic importance are limited to some eight or nine countries. The various types found, each with its own peculiar properties, are described, together with their mode of occurrence and methods of working. Strict temperature control in the calcining process is important in order that the products, caustic calcined magnesite and dead-burned magnesite, may be obtained in their optimum condition. The former is employed in the manufacture of magnesium oxychloride cements for composition floors, and the latter in refractories and as the starting point in the manufacture of magnesium metal. Sections are also included on dolomite and naturally occurring magnesium salts, the uses for which these are particularly adapted being described. The publication, which concludes with a selected list of references to the technical literature, should prove of considerable value to those specially interested in light metals or refractory materials.

PORTEVIN, A. "*Introduction to the Study of Heat Treatment of Metallurgical Products.*" First Edition, 8vo, pp. viii + 246. Illustrated. Cleveland, Ohio, and London, 1939 : Penton Publishing Co. (Price 22s.)

Professor A. Portevin is well known to metallurgists throughout the world for his valuable contributions to the advancement of the science, and in 1935 the position that his work had gained for him in this country was acknowledged by the presentation of the Bessemer Gold Medal. With his various collaborators he has carried out many

important investigations on different aspects of metallurgy, but his favourite field of research has been heat treatment, and he is regarded as one of the greatest authorities on this. The appearance of a book on this subject by Professor Portevin is therefore sure to arouse a considerable amount of interest, and it is unfortunate that the present work does not do justice to the author nor fulfil the expectations which the association of the title and author awakens. In view of the author's complete understanding of the subject with which he deals, it need hardly be said that the matter contained in the book is sound, relevant and suitably selected, but it does not seem to be presented in a way that is easy to follow. Although books are frequently read by people who are already familiar with some or all of the ground they cover (and reviewers are generally drawn from this class) the primary object of a book is either to provide a classified collection of information to which anyone may refer when the need arises, or a systematic account that will instruct the uninformed. From the title, the foreword and the contents of the present work it is evident that it is intended to function as a book of elementary instruction, and with due respect to the eminence of the author and full appreciation of the profound understanding of the subject displayed in the book, it must in fairness be said that it would be very difficult for anyone with no previous acquaintance with the theoretical side of heat treatment to gain the knowledge he seeks from this work. It is true, of course, that between novices on the one hand and experts on the other, there are many who will benefit from the reading of this book, and the advantage they derive will increase to a maximum and then decrease as their previous acquaintance with this and associated subjects becomes greater. But even from this point of view, more careful consideration of the order in which points are dealt with, of the length and contents of a given description, and of the standard of knowledge assumed in the reader, would have increased the value of the book. As would be expected, most of the book is concerned with the heat treatment of steel, which is dealt with in six chapters respectively entitled: Transformation Points in Steel; Preliminary Treatment of Steel; Phenomena and Mechanism of Steel Quenching; Quenching; Tempering; and Classification of Industrial Steels. Following these there is a chapter on Annealing in which this subject is dealt with generally. After that there are two chapters devoted respectively to Malleabilisation of Cast Iron and Heat Treatment of Light Aluminium Alloys, and the book is concluded with a chapter of General Remarks. There are no micrographs, the structure being represented by sketches, and nearly all the references are to publications with which the author's name is associated. Despite what has been said about faults in the presentation, the book can be recommended as a thoughtful and authoritative commentary on a subject with which the author is thoroughly familiar.

J. M. ROBERTSON.

MINERAL RESOURCES

(Continued from p. 57 A)

The Chrome-Ore Reserves of Eastern Rhodopen in Bulgaria. W. E. Petrascheck. (Zeitschrift für praktische Geologie, 1939, vol. 47, Apr., pp. 61–67). A geographical and geological description is given of the chrome-ore beds of south-eastern Bulgaria.

Coal in Sardinia. (Iron and Coal Trades Review, 1939, vol. 138, May 19, p. 875). An abridged version of a report by D. Sandulli of the Italian National Association for the Control of Combustion is presented in which information is given concerning the Sulcis coal-field in south-west Sardinia. During the war an annual production of 65,000 tons was obtained; this declined in the post-war period to 15,000 tons, but has again advanced to about 53,000 tons in 1934. A greatly increased production is planned, and it is intended to start up shortly a large modern washing plant at Serbariu capable of treating 4000 tons of coal per day. Data concerning the seams, the analyses of the coal and size and depth of the shafts are given.

Note on the Manganese Ores of L'Imini (Morocco). R. Zvéreff. (Annales des Mines, 1939, vol. 15, May, pp. 115–122). A brief report is presented of a petrographic examination made by the École des Mines, Paris, on some samples of manganese ores received from the district south of the Atlas Mountains in Morocco.

Geology of the Iron Ore Deposit of Ninghsiang, Hunan. Y. L. Wang, T. Y. Liu and Y. C. Cheng. (Bulletin of the Geological Survey of China, 1938, Dec., No. 32, pp. 1–11). The authors present an account of the iron ore deposits in the hilly country in the western part of the Ninghsiang district of China. The occurrences are scattered over a wide area, but in some places the seams are over 1 m. thick. The iron content varies between 19% and 54% and the total reserves are estimated to be 11,750,000 tons.

Known Iron Ore Reserves of the World and Their Significance. C. Hart. (Iron and Steel Engineer, 1939, vol. 16, May, pp. 42–61). The author presents a comprehensive review of the known iron ore reserves of the world, classifying them by countries and giving numerous tables of analyses and quantities produced annually. In the concluding part of his paper he considers the geographical position of the ore deposits in relation to armament manufacture.

ORES—MINING AND TREATMENT

(Continued from pp. 58 A–59 A)

Sinter—Facts and Fancies. P. G. Harrison. (Eastern States Coke-Oven and Blast-Furnace Association, Mar., 1939: Blast Furnace and Steel Plant, 1939, vol. 27, Apr., pp. 372–374, 411; May, pp. 492–493, 515–516; June, pp. 604–605, 616–617). The author explains in Part I. the theory of sintering ores and describes some of the difficulties encountered in the process. He discusses some of T. L. Joseph's conclusions regarding the reducibility of ores, which show that in the laboratory the reducibility of ores is almost entirely a function of their permeability to gas. As, however, the permeability determination is difficult, porosity tests are carried out, and the results are used as an index of reducibility. The author points out that when applying T. L. Joseph's results it should be remembered that these are based on the scientific aspect of reducibility based upon the rate at which oxygen is eliminated from an ore, whilst the blast-furnace operator measures reducibility as the amount of coke required to produce a ton of pig iron. In Part II. the author points out that in the laboratory the reducibility is considered as a function of the ratio of surface to mass. He then reverts to the blast-furnaceman's more practical standpoint, and discusses the use of sinter for two purposes, first, in relatively small quantities in conjunction with other ores in order to improve the mass permeability of a furnace burden or in order to add certain metallic or slag-forming elements, and secondly, when used as the major portion of a blast-furnace burden. In Part III., which concludes the series, he discusses the experience of the Alan Wood Steel Co. in the preparation and use of sintered ores, and presents a table of operating data relating to sintering plants at twenty-two American steelworks.

A Standard Specification for Agglomerate. K. V. Messerle and B. M. Nosovitskiy. (Metallurg, 1938, No. 11, pp. 57–67). (In Russian). After briefly considering the working of agglomerating plants producing iron-ore agglomerate for blast-furnaces, the authors examine the physico-mechanical properties and chemical composition of this product and the possibility of standardising these characteristics. Numerous practical data are given by way of illustration to the discussion.

The History of the Development of the Magnetising Roasting of Iron Ores. W. Luyken. (Stahl und Eisen, 1939, vol. 59, July 20, pp. 841–845). The author traces the development of processes for the magnetising roasting of iron ores from Edison's patent of 1888 up to the present time.

FUEL

(Continued from pp. 131 A–132 A)

Sulphur in the Products of Combustion of Fuels. L. R. Burdick and J. F. Barkley. (United States Bureau of Mines, 1939, May, Information Circular No. 7065). The authors present a review of the literature on sulphur in products of combustion with particular reference to the proportions of the total sulphur in the original fuel which (*a*) remain in the ash, (*b*) lodge in the fuel-burning equipment, and (*c*) escape to atmosphere.

Luminous Flame and its Applications. J. E. Dare. (Industrial Heating, 1939, vol. 6, Apr., pp. 308–312; June, pp. 508–510: Heat Treating and Forging, 1939, vol. 25, Apr., pp. 200–203, 207). The author discusses the factors which control the luminosity of gas flames used for industrial heating purposes and the advantages of combustion with a luminous flame as compared with a non-luminous flame, and gives some general information on the application of the luminous flame and the design of burners.

Coal Washing with Dense Media. C. W. H. Holmes. (Colliery Engineering, 1939, vol. 16, June, pp. 207–208, 212). After a brief description of the Staatsmijnen-Loess system of coal washing, a full description of which has already appeared in several journals (*see* p. 63 A), the author discusses its novel features and considers the possibility of applying them to coal-washing in Great Britain.

A Washability Study of the Woodstock Coal Bed at Klondyke Mine, West Blocton, Ala. B. W. Gandrud and G. D. Coe. (United States Bureau of Mines, 1939, May, Report of Investigations No. 3449).

Classification and Tabling of Table Middlings at the Colta Coal Washery, Flat Creek, Ala. B. W. Gandrud, G. D. Coe and H. J. Hager. (United States Bureau of Mines, 1939, May, Report of Investigations No. 3448).

The Nature and Treatment of Washery Water. W. Lomax and J. C. F. Statham. (Colliery Engineering, 1939, vol. 16, Apr., pp. 124–127, 137; May, pp. 164–168; June, pp. 225–231). In the first part of their paper the authors consider how to control the concentrations of solids in coal-washery water by treating the whole of the circulating water, and by drawing off continuously for treatment a predetermined fraction of the water. They describe next a series of tests on samples of the inlet and outlet water passing to and from the settling tank; these samples were taken twice daily from a Baum type washer designed for a throughput of 120 tons per hr. The specific gravity, total solids, percentage of ash in solids, sieve

analyses, and hardness of the water were determined. The results showed that the hardness of the water has a very marked effect on the nature of the effluent and a hard-water supply is desirable. In the second part the authors consider in detail the theory of the action of flocculants in increasing the settling rates of suspensions and how this process is sometimes accelerated and sometimes retarded by the addition of electrolytes. In the third part the authors discuss the design of settling tanks, filters and thickeners, and the factors which affect the rates of settling and filtration.

The Brancepeth Pulverite Works. (Iron and Coal Trades Review, 1939, vol. 138, June 16, pp. 1032–1033: Engineer, 1939, vol. 167, June 16, pp. 746–747). **New Pulverised Fuel Works at Brancepeth, Durham.** (Colliery Guardian, 1939, vol. 158, June 23, pp. 1091–1094: Metallurgia, 1939, vol. 20, June, pp. 81–83). **A Modern Pulverised Fuel Plant.** (Iron and Steel, 1939, vol. 12, July, pp. 638–639). In order to supply small industrial consumers of fuel with pulverised coal at an economic price, a plant has been erected at the Brancepeth Colliery, County Durham, with two units for the production of 1250 tons per week each of "Pulverite," as the new fuel is called. A brief description of the works with illustrations is here presented. It is interesting to note that provision has been made for both road and rail transport; for the former a special tank mounted on a lorry is used from which the fuel can be discharged direct into the hopper at the consumer's works through a pipeline by compressed air, the compressor unit being driven from the lorry engine.

Carbonizing Properties and Petrographic Composition of Washed and Unwashed Lower and Upper Kittanning Bed Coals from Mines 72 and 73, Johnstown, Cambria County, Pa. A. C. Fieldner, J. D. Davis, R. Thiessen, W. A. Selvig, D. A. Reynolds and C. R. Holmes. (United States Bureau of Mines, 1939, Technical Paper 595).

By-Product Coke Plant at Hanna Furnace Division, Great Lakes Steel Corporation. C. P. Betz and P. C. Vetter. (Iron and Steel Engineer, 1939, vol. 16, June, pp. 2 G.L.–16 G.L.). The authors describe in detail, with numerous illustrations, the new coke-oven and by-product plant of the Great Lakes Steel Corporation near Detroit. There are 130 underfired regenerative ovens, each 42 ft. 9½ in. long, 13 ft. 5½ in. high, 15½ in. wide at the pusher end, and 18½ in. wide at the discharge end.

Coke-Oven Modernisation at Mitchell Main Colliery. (Coke and Smokeless-Fuel Age, 1939, vol. 1, June, pp. 14–16). An illustrated description is given of the new coke-oven and by-product plant installed at Mitchell Main Colliery in South Yorkshire. The plant replaced by the new ovens consisted of 45 regenerative ovens taking a charge of 8 tons each and requiring 36 hr. for carbonisation. The new battery comprises only 20 Simon-Carves ovens taking a charge of 15 tons each, which can be carbonised in 18 hr. Each oven is 38 ft. 5 in. long, 13 ft. 3 in. high, and 18 in. wide.

Wilputte Issues a White Paper. L. Wilputte. (Blast Furnace and Steel Plant, 1939, vol. 27, May, pp. 471–486). The author discusses the design and operation of the modern Otto-Wilputte coke-oven, and also comments on F. Denig's paper, "Modern Coke-Oven Design and Practice," which appeared in Iron and Steel Engineer, 1938, vol. 15, Oct., pp. 32–51. (*See* Journ. I. and S.I., 1939, No. I., p. 9 A).

Power, Material and Process Investigations at Coke-Ovens in the Saar District. E. Senfter. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, July, pp. 1–12). The author reviews and discusses data relating to the operation of several new batteries of coke-ovens which have been put in commission in the Saar district during the last few years. The general conclusion at which the author arrives is that the most economical method of working in the Saar district is to ram the charge and use a reduced area of contact between the charge and the wall. This is in contrast to the procedure in the Ruhr district, where the ovens are charged to a higher level.

The Anticipation of Coke-Plant Accidents. C. Koons. (Proceedings of the American Gas Association, Twentieth Annual Convention, 1938, pp. 631–637). The author analyses the causes of accidents which occur at coke-oven plants and discusses methods of accident prevention with particular reference to the training of workmen.

The Improvement of the Physico-Mechanical Properties of Coke. A. Bruk and B. Shtromberg. (Stal, 1938, No. 11, pp. 1–5). (In Russian). Some Russian work on the selection of coal with suitable properties for coking and the blending of different grades of coal is briefly reviewed. The addition of finely ground coke and of non-coking coal to the charge, as well as the use of blast-furnace gas for heating, have a beneficial effect on the mechanical properties of the coke obtained. These properties are more accurately characterised by the extent and nature of the cracks and by the granulometric composition of the coke than by the drum test.

The Refining of Low-Temperature-Distillation Tar by Subsequent Thermal Treatment. A. Jäppelt and A. Steinmann. (Glückauf, 1939, vol. 75, July 8, pp. 596–601).

Applications of Gas Fuel for Foundries. A. E. Wilson. (Foundry Trade Journal, 1939, vol. 60, May 25, pp. 417–418). The author discusses the application of gaseous fuel for lighting cupolas, heating ladles, and drying moulds and cores, and describes some devices which increase the efficiency of the drying stoves.

PRODUCTION OF IRON

(Continued from pp. 133 A–135 A)

Hamilton Works of the Steel Company of Canada, Limited. (Iron and Coal Trades Review, 1939, vol. 138, June 23, pp. 1082–1083). An illustrated description is given of the co-ordinated iron and steel works of The Steel Company of Canada Ltd., at Hamilton. At this works there are eighty 13-ton Wilputte regenerative coke-ovens, two blast-furnaces, four 50-ton, four 100-ton and three 175-ton steel furnaces, a complete sheet mill, three merchant bar mills, annealing furnaces and galvanising pots, and a modern testing laboratory.

Construction of the New 1000-ton Blast Furnace at Great Lakes Steel Corporation. R. M. Hughes and W. J. Rees. (Iron and Steel Engineer, 1939, vol. 16, June, pp. 18 G.L.–30 G.L.). The authors present a detailed and illustrated description of the new blast-furnace on Zug Island near Detroit at the works of the Great Lakes Steel Corporation. This furnace has been in blast since August 1938, and is capable of producing 1000 tons of pig iron per day. Among the interesting data given, it may be noted that 1765 lb. of coke is used per ton of iron produced and the blast required amounts to 64,000 cu. ft. per min.

New Blast-Furnace Gas-Washer Highly Efficient. B. B. Frost. (Blast Furnace and Steel Plant, 1939, vol. 27, June, pp. 569–571). The authors describe the gas-washing plant recently put in commission at the Donner Plant of Republic Steel Corporation in Buffalo. Owing to lack of space, it was decided to remodel the existing primary tower washers into single-stage McKee-type washers, and to erect Cottrell precipitators for final cleaning on top of these washers so that raw gas from the dust-catcher would be cleaned in one pass through a combination unit. Each of the Cottrell units is capable of cleaning 55,000 cu. ft. of blast-furnace gas per min., and the exit gas contains not more than 0·025 g. of solids per cu. ft. The author presents data concerning the power consumption, costs and rating of the plant.

The Pig-Iron Casting Machine at the Duisburg Kupferhütte. A. Koch. (Stahl und Eisen, 1939, vol. 59, June 29, pp. 749–753). After pointing out why the use of casting machines for pig iron has not advanced so much in Germany as in other countries, the author shows that the conditions at the Duisburg Kupferhütte appeared to favour the use of such a machine. He then describes the machine in detail. It consists of two endless chains of moulds running side by side. The overall dimemsions of the machine are 54 m. long by 10 m. wide. Each chain carries 296 moulds weighing 140 kg. each.

The speed of each chain can be controlled independently and varied between 6·2 and 9·3 m. per min. Each chain is driven by a 25-h.p. motor. The rate of casting averages 2 tons per min. In conclusion the author discusses some of the results obtained and the costs of working the machine for seven months. The management consider that the use of this machine has resulted in improving the quality of the iron produced and in lowering the costs.

Burning of the Tuyeres of Blast-Furnaces. N. Goldshteyn, B. Gess and S. Kozakov. (Stal, 1938, No. 12, pp. 1–5). (In Russian). Investigations into the causes of the excessive burning of the tuyeres at two works are described. The main causes at the first works were the presence of very basic slags, which tended to vary considerably in composition and viscosity, and the comparatively low quality of the coke. At the second works the burning was due to the tendency of the reaction in the furnace to take place near the periphery, this in turn being due to the adoption of a charging sequence unsuited to the sinter which was being used, and in some cases to insufficient blast. Remedial measures are suggested for both cases.

The Unification of the Burden of Blast-Furnaces at the Ordzhonikidze Works. S. Koptevskiy. (Metallurg, 1939, No. 2, pp. 42–52). (In Russian). One of the chief causes of the erratic operation of the blast-furnaces at the Ordzhonikidze works is the irregular evolution of large quantities of flue dust. In an attempt to find the reason for the formation of excessive quantities of flue dust, the nature of the ore and of other raw materials, as well as of the flue dust itself is scrutinised and several other relevant factors, such as the effect of atmospheric moisture and the distribution of the constituents of the burden during charging into the furnace, are considered. It is concluded that low quality of the ore and coke is chiefly responsible. Suitable grading, moistening (so as to obtain 6–7% of moisture) and minor changes in operating practice are suggested to improve matters.

Short-Time Repairs of Blast-Furnaces at the Kuznetskiy Metallurgical Works. N. Kratenko. (Stal, 1938, No. 11, pp. 9–15). (In Russian). The methods adopted for effecting minor repairs to the lining and for removing scaffolding from the walls of the upper part of the stack are described. The scaffolding is removed by blasting with ammonal.

Blast-Furnace Performance Improved. H. V. R. Iyenger. (Blast Furnace and Steel Plant, 1939, vol. 27, June, pp. 607–608). The author describes how the production of the charcoal blast-furnace at Bhadravati, Mysore, was controlled to suit market conditions by altering the size of the tuyeres and the volume of blast. The furnace was designed for an output of 80 tons per day, and it was found possible to control the production between 60 and 100 tons per day.

The Ladles of Slag Cars. L. Eydel'nant. (Stal, 1938, No. 11, pp. 15–18). (In Russian). The occasional very rapid failure of

cast-iron slag ladles is due to cracking caused by a combination of the mechanical and thermal stresses to which they are subjected in use. Attempts to prolong the life of these ladles by the use of special thick-walled designs and by varying the chemical composition of the cast iron were not very successful. Following development in America, a number of cast-steel slag ladles were made and have given very good service. The composition and mechanical properties of the steel used are given and the adoption of the conical ladle design with corrugated sides is recommended in spite of its more difficult production.

Decarburisation of Granulated Pig-Iron—The "R. K." Process. Bo Kalling and I. Rennerfelt. (Jernkontorets Annaler, 1939, vol. 123, No. 3, pp. 115–154). (In Swedish). The authors give an account of the theoretical considerations, laboratory tests and the full-scale method of production which they have developed in Sweden, whereby pig iron is converted into a product of low carbon content which is suitable as a substitute for steel scrap for remelting in steel furnaces. The process, called the "R.K." Process, is in two stages: first that of granulating the iron, and secondly that of decarburising the granules. At the works of Fagersta Bruks Aktiebolag, where this process is being used, the granulator consists of a water-tank 3100 mm. long by 1700 mm. wide, on top and at one end of which is a reservoir into which the molten iron is transferred from the blast-furnace by a ladle. A hole in the reservoir permits a constant stream of the metal to fall on to a revolving wheel carrying wooden blades. A stream of water falling on the wheel prevents the blades from catching fire. This wheel revolves above the surface of the water in the tank at about 300 r.p.m., and the blades shatter the stream of metal into fine particles which fall into the water and collect in a basket previously placed in the bottom of the tank. About 5 tons of pig iron are granulated at a time at the rate of about 200 kg. per min. Two kinds of iron are used at Fagersta, the analyses of which are: carbon 4·5% and 4·3%, silicon 0·50% and 0·20%, manganese 1·25% and 0·35%, phosphorus 0·025% max., and sulphur 0·010% and 0·015% max., respectively. The decarburising plant at Fagersta is designed for a production of 6–10 tons per 24 hr., and it consists of a rotary furnace 4 m. long by 1050 mm. in dia. At the charging end there is an opening 350 mm. in dia. into which three concentric tubes project more than half the length of the furnace. The granulated iron is fed into the centre tube and is carried into the furnace, where it is decarburised without melting in a gas mixture containing carbon dioxide and carbon monoxide in such proportions that decarburisation takes place practically without simultaneous oxidation of the iron or other metallic constituents. The composition of the gas mixture in the furnace is controlled by burning the reaction gas leaving the charge and some blast-furnace gas with air, which is blown in a special way towards the inclined surface of the revolving charge. The gases are blown

in along the centre tube, primary air is blown along the inner annular space, and secondary air along the outer annular space. The furnace is revolved at about 3 r.p.m. and the temperature at the hottest part is about 1050° C. The consumption of blast-furnace gas is very low, as the process is exothermic, and in continuous service scarcely any addition of fuel is necessary if the carbon content of the product is not required to be specially low. Experience has shown that the carbon content of the product can easily be kept below 0·10% even when the production is brought up to 10 tons per 24 hr. The size of the granules is of great importance, and it has been found that when this is less than 2 mm. the average carbon content of the product is about 0·05%. The manganese content of the iron has little effect upon the process, but a very high phosphorus content results in longer time being required. The sulphur content of the product is slightly less than that of the raw material, and laboratory tests show that the addition of lime reduces the sulphur still farther. No figures relating to costs are given, but the capital and maintenance costs, fuel consumption, and wages are all very low.

Decarburisation of Granulated Pig Iron : The "R.K." Process. Bo Kalling and I. Rennerfelt. (Iron and Steel Institute, 1939, this Journal, pp. 137P–160P). This paper contains a complete account in English of the authors' new method, the "R.K." process, for converting pig iron into a product with a low carbon content, which is suitable as a substitute for steel scrap for remelting in steel furnaces. (*See* previous abstract).

In the paper the theory of the process is discussed, and the results are given of experiments in the laboratory and on a small technical scale, and from the first furnace operating on a full industrial scale.

Development and Present Position of Cost-Accounting and Profit and Loss Accounts in the German Iron and Steel Industry. H. Kreis. (Stahl und Eisen, 1939, vol. 59, July 13, pp. 815–818). The author presents a brief review of the stages by which the methods of cost-accounting in the German iron and steel industry have reached their present pitch of perfection.

FOUNDRY PRACTICE

(Continued from pp. 136 A–142 A)

A New Cupola-Melting Process. W. Zöller. (Giesserei, 1939, vol. 26, June 30, pp. 336–339). The author outlines a new method of melting iron in a cupola which is based upon principles quite different from those employed in standard cupola practice. He explains the principles of heat transfer by conduction and radiation, pointing out that both are functions of the temperature difference between the heat-emitting and the heat-absorbing bodies. In the former the heat transmission is proportional to the temperature difference, but in the latter it is proportional to the difference between the fourth powers of the absolute temperatures of the two bodies. In the new process the author makes use of the principles of radiation in transferring the heat from the coke to the iron by eliminating both the principle of opposing movement (the descent of the charge and the rise of the gases through it) and the alternate additions of coke and iron. In the author's process only one layer of iron is in the cupola at a time, and the coke (blown to white heat) lies on top of it, and the transfer of heat by radiation is assisted by one or more curved heat reflectors built into the upper part of the shaft. The efficiency of the cupola is also improved by causing the hot gases to pass through a blast preheater at the top of the shaft. Among the advantages claimed for the process are : (1) The melting time is reduced, and there is therefore less time for the iron to take up impurities (especially sulphur) from the coke ; (2) the amount of blast required can be calculated and adjusted to produce the most heat without waste ; (3) the products of combustion do not pass through the iron and do not affect it ; (4) it is very easy to change over from the melting of one kind of iron to another ; and (5) as the coke has not much weight to support, there is no objection to using a coke of low mechanical strength. The author presents data of the analyses and properties of iron produced by this process.

Foundry Mixtures for Alloy Cast Irons. H. Uhlitzsch and K. Appel. (Giesserei, 1939, vol. 26, May 31, pp. 266–273 ; June 16, pp. 310–318). From the results of over 140 experimental melts of various compositions of nickel-molybdenum and nickel-chromium iron, the authors construct composition diagrams for irons containing nickel 0·5% and 1·5%, molybdenum 0·25% and 0·75%, and chromium 0·5%, which produce pearlitic zones in specimens 30, 20, 10 and 6 mm. in dia. They also compare information on structures and analyses available in the literature, and establish the relation between the wall-thickness of a casting and the diameter of a test-

piece. They find that all three of the above alloying elements widen the pearlite zone, nickel moving the left boundary line farther to the left and the right boundary line farther to the right, whilst molybdenum, and to a still greater extent, chromium, move both boundary lines to the right. The authors also develop diagrams which show the relation between the quantities of nickel, molybdenum and chromium added, the carbon, the silicon, and the wall-thickness or diameter of specimen and the structure produced. In conclusion they discuss the effect of additions of these three metals on the structure and mechanical properties of cast iron.

Gray and Malleable Iron. E. Touceda. (Iron Age, 1939, vol. 143, June 22, pp. 27–31 ; June 29, pp. 21–23, 83). In the first part of this paper the author outlines the improvement which has taken place in the technique of the production of grey and malleable iron castings during the last thirty years. In the second part he considers the more recent improvements in greater detail, dealing in particular with annealing-furnace design and with the excellent mechanical properties which malleable iron produced by modern methods possesses.

Annealing Malleable Iron. W. F. Ross and H. H. Fairfield. (Canadian Metals and Metallurgical Industries, 1939, vol. 2, Apr., pp. 79–81, 89). **Fast Malleablizing.** (Steel, 1939, vol. 104, May 15, pp. 66–69, 78). **Short-Cycle Annealing of Malleable Iron.** (Metals and Alloys, 1939, vol. 10, May, pp. 142–143). The authors describe a furnace and equipment for annealing malleable iron castings. (*See* p. 70 A).

Presidential Address. W. B. Lake. (Institute of British Foundrymen, International Foundry Congress, London, June, 1939 : Foundry Trade Journal, 1939, vol. 60, June 15, pp. 499–500). The author, after welcoming the delegates to the International Foundry Congress, devoted his address to a review of the history of the manufacture of steel castings, in the course of which he dealt successively with the first attempts at steelmaking, the Bessemer process, the Stock converter, the open-hearth process, electric furnaces, and pulverised-fuel-fired rotary furnaces.

Converter Method of Steel Making. F. B. Skeates. (American Foundrymen's Association, Symposium on Steel Melting Practice, May, 1939, Preprint No. 11, pp. 71–77). The author describes the practice at an American steel foundry where two cupolas and two side-blown converters are used. His description includes particulars of the charge, the process of desulphurising in the ladle, the action of the charge in the converter during the blow, and the deoxidation, recarburisation and finishing processes. In conclusion he gives some data of the composition and properties of the steel produced.

Steel Foundry Basic Open-Hearth Practice. J. W. Porter. (American Foundrymen's Association, Symposium on Steel Melting Practice, May, 1939, Preprint No. 11, pp. 1–20). The author describes the basic open-hearth plant and process at the Granite City

Works of the American Steel Foundries. His description includes particulars of the construction of the furnace lining, composition of the charge, fuel consumption, procedure for adding alloys and analyses of the slag and steel.

Steel Foundry Acid Open-Hearth Practice. W. C. Harris. (American Foundrymen's Association, Symposium on Steel Melting Practice, May, 1939, Preprint No. 11, pp. 21–28). The author presents a brief account of the operation of an oil-fired acid open-hearth furnace in an American steel foundry.

Production Problems in Steel Castings. P. E. McKinney. (Foundry, 1939, vol. 67, June, pp. 36–38, 110). In this general discussion of some of the difficulties encountered in producing large steel castings the author deals in particular with methods of obtaining constant rates of solidification.

Modern Automotive Foundry Sand Practice. A. S. Nichols. (Transactions of the American Foundrymen's Association, 1938, vol. 46, pp. 916–930). The author presents data obtained from seven important American foundries respecting the methods they use for the production and control of the moulding sand required for making automobile castings.

The Effect of Different Electrolytes on the A.F.A. Clay Determination. J. F. Haseman. (Transactions of the American Foundrymen's Association, 1938, vol. 46, pp. 851–862). The author describes an investigation of specimens of 20 clay-bonded sands the A.F.A. (American Foundrymen's Association) clay content of which ranged from 6% to 39%. It was undertaken with the object of determining what effect electrolytes, other than sodium hydroxide, might have upon the clay determinations made by the A.F.A. method. The electrolytes tried were sodium hydroxide, sodium carbonate, sodium oxalate, sodium citrate, sodium pyrophosphate, and sodium silicate; solutions containing 1%, 3%, and 5% of the electrolyte were tried in each case. The results show that: (1) All the electrolytes except sodium silicate gave an increasing A.F.A. clay content with increasing strength of electrolyte up to 5%, although some samples behaved erratically; (2) in eight of the sands tested, sodium hydroxide gave the best results, and in some cases a slightly higher A.F.A. clay content was obtained with sodium pyrophosphate, sodium carbonate, and sodium oxalate, whilst sodium citrate gave consistently good results except in the case of one sand; and (3) the behaviour of sodium silicate was peculiar and inconsistent.

Iron Lining Fused to Steel Shell Centrifugally. A. H. Allen. (Foundry, 1939, vol. 67, June, pp. 30–33, 100, 102). The author describes the plant and processes used by the Centrifugal Fusing Co., Michigan, for the manufacture of automobile brake drums. The outer shell of the drum is made first from a length of hot-rolled steel strip the ends of which are electrically welded. The drum is upset to the required shape and diameter and is then cleaned with

steam and an alkali before being passed on to the foundry department. The foundry has no core room, moulding machines or sand-conveyor equipment. The iron requirements are met by one of two 54-in.-dia. cupolas which are water-jacketed round the melting-zone. The iron is tapped at 2750–2800° F. into a 4-ton, heavily insulated, forehearth ladle, whence it is poured into a 2000-lb. transfer ladle for conveyance to an electric duplexing furnace. The carbon and silicon of the iron produced are kept at 3·55–3·65% and 2·12–2·24%, respectively. Near the electric furnace are two turn-tables each carrying eighteen centrifugal casting machines or "spinners." A runner box is attached to the door of each spinner, and this holds exactly the amount of iron required to line the brake drum, which has been previously inserted by an operator. Cam devices close and open the doors of the spinners and switch on and off the current required to spin the drum. Each turn-table revolves once every 3 min. and requires only five men to operate all the spinners. To ensure complete fusion between the iron and the steel shell, the latter is heated to 400° F. and coated on the inner surface with a flux of borax and soda ash before being put in the spinner. The normal output of this plant is about 11,000 double rings per 8-hr. shift.

Centrifugal Casting of Metals and Alloys. J. E. Hurst. (Iron Age, 1939, vol. 143, June 29, pp. 17–20; vol. 144, July 6, pp. 51–53). In the first part of this paper the author, after briefly tracing the history of centrifugal casting from a British patent dated 1809, describes the different methods of applying the principle which are in use to-day. He does this under three sections: (*a*) The means adopted for rotating the mould; (*b*) the methods of introducing the metal into the mould; and (*c*) the form and construction of the mould. In the second part he describes a number of processes in which either revolving pourers or moulds are used for the purposes of refining pig iron. In all these the same principle applies, which is that the rotation of the molten metal causes the gases, sulphides and slag to collect at the base of the paraboloid depression on the surface, where, with the exception of the gas, they remain after the rotation stops, and then by careful pouring or by bottom-pouring the purified metal can be drawn off.

The Effect of Casting Temperature on the Primary Microstructure of Cast Irons. Theories of Dendrite Formation and of the Solidification of Iron-Carbon Alloys. A. L. Norbury. (Iron and Steel Institute, 1939, this Journal, pp. 161P–175P). Treatments of the melt which coarsened or refined the graphite eutectic structure in grey cast irons were found to have no corresponding effects on the iron-carbide eutectic in white cast irons. Differences in casting temperature, however, produced remarkable differences in the *primary* microstructure. In *hyper*eutectic white iron compositions, lower casting temperature greatly reduced the size of the primary carbide plates. In *hypo*-eutectic white iron compositions, it refined the

dendritic structure of the primary austenite, so that it became replaced by a globular austenite structure. The microstructures are interpreted as showing that primary dendrites result from the joining up of globules, and that large primary plates result from the joining up of smaller plates. This may have a bearing on the "mosaic" structure in crystals. Lower casting temperature refined the dendritic structure of ordinary (γ-iron) compositions of grey cast iron in a similar manner. In the case of 14% silicon (δ-iron) grey iron compositions, however, it had no refining effect comparable with the above. This difference is attributed to the recrystallisation of γ-iron on solidification, due to the occurrence of the $\delta \rightarrow \gamma$ allotropic change and to the non-recrystallisation of δ-iron, both being assumed to be in the δ-iron allotropic condition in the liquid state. In the same way, it is suggested that pure carbon is in the diamond allotropic form in the liquid state, and solidifies without allotropic change when diamond is formed but with allotropic change when graphite is formed. In cast iron compositions, carbon is similarly assumed to be in the diamond form in the liquid state and to form a diamond-iron compound (iron carbide) when it solidifies without allotropic change, but to form graphite, as above, when it solidifies with allotropic change.

In an Appendix, it is suggested that elements in solid solution graphitise cast iron, while those forming compounds stabilise the carbide.

PRODUCTION OF STEEL

(Continued from pp. 143 A–147 A)

Control of Steel Quality in Integral Production. H. A. Dickie. (Metal Treatment, 1939, vol. 5, Summer issue, pp. 53–57). The author discusses the production of good quality steel at an integral steelworks, dealing with the subject in the following stages of production: (1) Selection and preparation of ores and other raw materials; (2) blast-furnace practice, including treatment of the iron after leaving the blast-furnace, and mixer practice; (3) steel-furnace practice; (4) deoxidation and casting practice; (5) primary treatment of the cast product; and (6) treatment of the semi-finished product.

Possibilities of Increasing the Capacity of Steel Works. G. Bulle. (Stahl und Eisen, 1939, vol. 59, July 13, pp. 809–814). The author considers the measures which could be taken to increase the production of steel by the Bessemer, open-hearth and electric processes in Germany. He shows that the basic Bessemer process is relatively the most productive, and suggests the use of the duplex process as a means of increasing the capacity of open-hearth and electric furnaces.

South Works of the United States Steel Corporation near Chicago. C. Longenecker. (Stahl und Eisen, 1939, vol. 59, June 15, pp. 701–710). An abridged translation into German of the description of the South Works of the Carnegie-Illinois Steel Corporation which appeared in Blast Furnace and Steel Plant, 1938, vol. 26, Aug., pp. 786–822. (*See* Journ. I. and S.I., 1939, No. I., p. 16 A).

The Acid Bessemer Process of Steel-Making. T. Swinden and F. B. Cawley. (Iron and Steel, 1939, vol. 12, June, pp. 593–599). The authors conclude their series of articles describing the acid Bessemer plant and process as worked by the Workington Iron and Steel Co. by discussing the properties of the steel produced. (*See* p. 77 A).

Experimental Open Hearth. H. K. Work and M. H. Banta. (Steel, 1939, vol. 104, June 4, pp. 62–64, 76). The authors describe the 1-ton experimental steel furnace installed by the research department of the Jones and Laughlin Steel Corporation. (*See* p. 78 A).

Practice in the Manufacture of Rimming Steel. (Ninth Report on the Heterogeneity of Steel Ingots, Iron and Steel Institute, 1939, Special Report No. 27, Section IV.). This Section of the Report contains nine papers describing practice in the manufacture of rimming steel as carried out in plants in Great Britain; the tenth paper

gives a general survey of the practical aspects of making this class of steel, based on the preceding contributions. The papers are as follows :

The Manufacture of Rimming Steel at Workington by the Acid Bessemer Process, by T. Swinden and F. B. Cawley.
The Manufacture of Rimming Steel by the Basic Bessemer Process at Corby, by W. B. Kerlie.
The Manufacture of Rimming Steel at Templeborough, by N. H. Bacon.
The Manufacture of Rimming Steel at the Irlam Works of the Lancashire Steel Corporation, Ltd., by D. Binnie.
The Manufacture of Rimming Steel at the Normanby Park Steel Works, by J. B. R. Brooke.
Notes on the Practice of Making Rimming Steels at the Cardiff Works of Guest Keen Baldwins Iron and Steel Co., Ltd., contributed by the Company.
Rimming Steel Practice at Glengarnock Iron and Steel Works, by J. Gibson.
Some Notes on the Manufacture of Rimming Steel at Briton Ferry, Using Cold Pig Iron and Scrap in the Basic Open-Hearth Furnace, by J. S. Lewis.
Rimming Steel from Basic Open-Hearth Furnaces at Bilston, by R. S. Rolfe.
General Survey of the Practical Aspects of Rimming Steel Manufacture, by J. Mitchell.

This general study of practice in the preparation of rimming steel in Britain throws into relief the essentials of successful operation. In the first place, the furnace practice must be such that the material is prepared by means of a properly controlled boil. The importance of accurate control, usually effected through the slag composition and judicious use of deoxidisers, is clearly brought out. The production of rimming steel is an art demanding accuracy of control, and this product is not, as is sometimes too loosely assumed, a material melted and cast into moulds at random with a minimum of finishing addition.

The Surface Reaction Method. W. Engels and N. Engels. (Metallwirtschaft, 1939, vol. 18, June 9, pp. 479–482). An abridged German translation of a paper on a new surface-reaction process for the direct production of steel from ore. This appeared previously in Ingeniørvidenskabelige Skrifter, 1938, B, No. 10. (*See* Journ. I. and S.I., 1939, No. I., p. 274 A).

Residual Metals in Open-Hearth Steel. J. D. Sullivan and A. E. Pavlish. (Metals and Alloys, 1939, vol. 10, June, pp. 184–186). The authors present an analysis of statistics supplied by the leading American steel-producing companies which shows the average percentages of residual nickel, copper, tin, chromium, and manganese in the steel produced by them for the years 1930 to 1938. The

determinations were made from plain carbon steel in the various plants before adjustment of the composition by alloy additions. The figures indicate that increases in residual metals have been negligible, and there appears to be no danger of these elements getting out of control. It has therefore been decided to discontinue the study for about five years.

Design Characteristics and the First Operating Results of No. 6 Open-Hearth Furnace of the Zaporozhstal' Works. M. Savos'kin. (Stal, 1938, No. 11, pp. 22–25). (In Russian). The author describes the design and equipment of one of the open-hearth furnaces at the Zaporozhstal' works, and presents a table giving data concerning the raw materials and operating conditions for five heats.

The Ferrous-Oxide Content of the Metal During the Open-Hearth Process. P. N. Ivanov. (Metallurg, 1938, No. 2, pp. 31–41). (In Russian). An attempt is made to survey and correlate earlier work on the ferrous oxide content of steel in the open-hearth process, the various contradictions being eliminated by making use of results of the author's own experimental work. The information available regarding the variation during the open-hearth process of the ferrous-oxide content, the effect upon it of temperature and the rate of carbon elimination are considered. The drop in the ferrous-oxide content in the initial stages of melting is ascribed to the reduction in the amount of hyper-equilibrium ferrous oxide involved in the determinations as the temperature rises. At " normally elevated " temperatures the ferrous oxide content determined corresponds almost exactly to the equilibrium concentration. This change in the ferrous-oxide concentration and its subsequent increase as the temperature is raised further are explained by the change in the partial pressure of the carbon monoxide in the metal on passing from the lower to the normal temperatures, the partial pressure becoming stabilised as the temperature rises further. The change in the partial pressure of the carbon monoxide is in turn conditioned by changes with temperature of the viscosity of the slag. Field tests confirmed Körber's statement that the ferrous-oxide content is lowered as the rate of carbon elimination increases. The latter factor actually increases the hyper-equilibrium concentration (in accordance with the law of mass action) while it lowers the equilibrium ferrous-oxide concentration, this being due to a reduction in the partial pressure of the carbon monoxide within the metal. In conclusion factors limiting the rate of elimination of the carbon in open-hearth melting are considered.

The Manganese-Sulphide/Calcium-Oxide System at Medium and High Temperatures. D. Mirew. (Archiv für das Eisenhüttenwesen, 1939, vol. 12, May, pp. 529–531). The author describes a laboratory investigation which had the object of determining whether any reaction took place at medium or high temperatures between manganese sulphide and calcium oxide when mixed in different molecular proportions, and thus to ascertain the desulphurising

action of the manganese when working with a basic slag. The experiments were carried out at temperatures from 500° to 1600° C. He presents the results in tables and graphs, and his general conclusion is that any appreciable desulphurisation will only take place in the absence of basic slag containing lime ; if, however, there is any free lime present, this will act as the desulphurising agent.

Classification of the Direct Process under Materials, Power and Operating Conditions. H. Bansen. (Stahl und Eisen, 1939, vol. 59, July 6, pp. 785–790). The author explains and discusses methods of calculating costs in the Krupp-Renn direct process of steelmaking. He deals with the costs in consecutive stages from ore to ingot and compares the direct process with other processes of smelting Salzgitter ores.

The Behaviour of Hydrogen in the Electric-Furnace Melting of Steel. N. Chuyko. (Stal, 1938, No. 11, pp. 36–40). (In Russian). Referring to his earlier work, the author shows how analytical data, which he gives to illustrate the variation in the hydrogen content of the steel during the melting process, can be explained, and in some cases calculated, on theoretical grounds. A marked absorption of hydrogen takes place during the actual melting, whilst removal of hydrogen occurs during the boil, which should be of a suitable intensity and duration in order that maximum removal of the gas may be effected. The rate of removal of hydrogen is directly proportional to the square of the hydrogen concentration in the metal and inversely proportional to the square of the solubility constant of the gas in the metal. Some of the experimental results confirmed the theory that hydrogen-containing steel tended to be flaky. With the obviously desirable object of reducing the hydrogen content of the steel as much as possible, its partial pressure in the furnace atmosphere should be kept as low as possible (*a*) by the use of thoroughly dried materials, (*b*) by dilution with other gases (this can be achieved by the addition of limestone in electric-furnace melting), and (*c*) by the use of fuel with a low hydrogen content, *e.g.*, coal or coke dust in the open-hearth process.

Acid Electric Furnace Practice. W. Finster. (American Foundrymen's Association, Symposium on Steel Melting Practice, May, 1939, Preprint No. 11, pp. 59–70). The author presents some data on the number and capacity of electric furnaces in America which show that in 1937 there were 264 electric arc furnaces and 18 induction furnaces ; of these nearly one-half are of 1½–3 tons capacity. He then describes the construction of a 3-ton acid Moore Lectromelt furnace with a lifting and swinging roof, and the melting practice employed at a steel foundry using this type of furnace.

Basic Electric Practice for Steel Castings. C. W. Briggs. (American Foundrymen's Association, Symposium on Steel Melting Practice, May, 1939, Preprint No. 11, pp. 29–58). The author presents a comprehensive account of the melting practice at an American steel foundry where a basic electric-arc furnace is used. He discus-

ses the following items in detail: (1) Furnace linings and materials; (2) charging and melting; (3) double-slag practice; (4) single-slag practice; (5) hot-metal charge practice; (6) alumina-slag method; (7) manufacture of carbon and alloy steels by the basic process; (8) deoxidation and degasification; and (9) reactions of oxidation and reduction.

Induction Furnace Practice in the Steel Foundry. G. F. Landgraf. (American Foundrymen's Association, Symposium on Steel Melting Practice, May, 1939, Preprint No. 11, pp. 78–84). The author discusses induction-furnace steelmaking in general and takes a 1000-lb furnace as a typical example. Data are given concerning power consumption, lining, temperature, composition of heats, melting process, losses, &c.

Some Electrical Characteristics of a Miguet-Perron 10,000 kW. Furnace. I. Kirichenko. (Stal, 1938, No. 12, pp. 51–55). (In Russian). The author points out that the inductive resistance of the furnace, the accessory equipment and the so-called "active resistance" of the furnace circuit are not constant, as is generally assumed. An attempt is made to arrive at the limiting values of these resistances for the type of 10,000-kW. Miguet-Perron furnace used at the Zaporozhstal' ferrous alloy works. The inductive resistance determined experimentally was higher than the calculated value, varying between 135×10^{-6} and 145×10^{-6} ohms when melting 45% ferro-silicon. The average "active resistance" was 48×10^{-6} to 50×10^{-6} ohms, but it may vary between 44×10^{-6} and 54×10^{-6} ohms. The optimum voltages for use under the above conditions are discussed.

The Problems of Load and Electrodes in Large Electric Arc Furnaces. S. von Hofsten. (Teknisk Tidskrift, 1939, vol. 69, Jan. 14, pp. 14–17). (In Swedish). The author discusses the power consumption of electric steel furnaces in relation to experience gained in the working of a 14-ton and a 7-ton electric arc furnace, and a 4½-ton H.F. furnace at Sandviken in Sweden. In the second part of his paper he compares graphite with Söderberg electrodes. The Söderberg electrodes are prepared by pressing the ready-mixed compound at 150° C. into a cylinder. This cylinder has internal radial ribs whose main object is to carry the current to the interior of the electrode, with the result that the compound is easily heated and carbonised. It has been found that the electrical resistance of a Söderberg sheathed electrode is only one-quarter of that of a graphite electrode. (A German translation of this paper appeared in Stahl und Eisen, 1939, vol. 59, June 22, pp. 735–736).

Design of Ingot Moulds. E. Gathmann. (Engineers' Society of Western Pennsylvania, March, 1939: Blast Furnace and Steel Plant, 1939, vol. 27, May, pp. 466–468, 513, 515). The author describes some of the causes of defective ingots of rimming and of killed steel.

Ninth Report on the Heterogeneity of Steel Ingots. (Iron and Steel Institute, 1939, Special Report No. 27). The present Report

is made up of four sections, the first of which is introductory in character. Section II. consists of a detailed survey of a recent paper by Hultgren and Phragmén entitled "The Solidification of Rimming Steel Ingots." (*See* Journ. I. and S.I., 1939, No. I., p. 214 A). Section III. contains a further study of the variation in composition from outside to centre of the basic-Bessemer steel ingot, details of which are given in the Sixth Report (I. and S.I., Special Report No. 9). Section IV. is made up of four parts, the first three of which contain descriptions of acid-Bessemer, basic-Bessemer, and basic-open-hearth practice, respectively, at various works in Great Britain; the fourth part, which concludes the Report, comprises a general survey of the practical aspects of rimming-steel manufacture. Separate abstracts of the last three sections of this Report will be found under the appropriate sections of this Bulletin.

Rimming Steel. Further Studies of the Composition Variation from Outside to Centre. T. Swinden. (Ninth Report on the Heterogeneity of Steel Ingots, 1939, Special Report No. 27, Section III.). In Section II. of the Seventh Report on the Heterogeneity of Steel Ingots was published a detailed study of the variation in carbon, manganese, sulphur and phosphorus in (*a*) a billet of open-hearth rimming steel containing 0·16% of carbon, and (*b*) an ingot of basic Bessemer steel, example No. 64, details of which are given in the Sixth Report. In the present paper details are given of a further examination of the same basic Bessemer ingot, in which the following supplementary data are now presented: (*a*) Inclusions, a detailed microscopical study; (*b*) Brinell hardness; (*c*) oxygen and nitrogen contents by the vacuum fusion method. In addition, a detailed study of a basic open-hearth rimming steel ingot has been made by the examination of cross-sections of a 10½-in. bloom at points corresponding to the top, middle and bottom of the ingot. These have been examined by (*a*) microscopical examination, (*b*) chemical analysis for carbon, manganese, sulphur and phosphorus contents, and (*c*) vacuum fusion tests for oxygen, hydrogen, and nitrogen. Consideration is then given to the factors influencing segregation of the elements in rimming steel, these results being discussed in the light of contemporary work.

A Review of A. Hultgren and G. Phragmén's Theoretical Discussion of the Progress of Solidification of Iron-Carbon-Oxygen Alloys. C. A. Edwards. (Ninth Report on the Heterogeneity of Steel Ingots, 1939, Special Report No. 27, Section II.). The author presents a survey of Hultgren and Phragmén's paper entitled "The Solidification of Rimming Steel Ingots" (*see* Journ. I. and S.I., 1939, No. I., p. 214 A), with the object of stimulating a discussion on the theoretical principles which underlie the freezing of rimming steel. After quoting Hultgren and Phragmén's theoretical discussion of the progress of solidification, the author considers the influence of varying percentages of oxygen and carbon upon the location and character of the blow-holes in rimming steel ingots.

He comes to the conclusion that it no longer seems necessary to postulate the presence of a chilling surface which will cause rapid cooling for the reactions giving rise to the liberation of gas to set in, and his theory is that as the oxygen-rich globules rise, a vigorous reaction takes place between them and the carbon in the main liquid, producing carbon monoxide and carbon dioxide; the ratio between these two gases will be largely determined by the amount of carbon in the main liquid and the rate of formation of a new liquid phase rich in ferrous oxide.

Cast Steel and Forged Steel. G. Delbart. (Bulletin de l'Association Technique de Fonderie, 1939, vol. 13, May, pp. 156–171). The author discusses the iron-carbon diagram, the cooling and homogeneity of ingots of killed steel, the factors affecting the fluidity of steel, the formation of pipe, the effect of inclusions, the heat treatment of steel, and how the quality of finished forgings and castings is influenced by all these items.

"Tailor-Made" Steels. T. Grey-Davies. (Sheet Metal Industries, 1939, vol. 13, June, pp. 747–749). Continuation of a series of articles (*see* p. 14 A). The author correlates the technique of deoxidising steel in the furnace and in the ladle, the occurrence of inclusions and the rimming action of an ingot while solidifying with the quality of the sheets rolled from the ingot with special reference to deep-drawing quality sheets.

Cracks and Hair-Line Defects in High-Duty Carbon Steel. S. Lifshits. (Stal, 1938, No. 11, pp. 19–22). (In Russian). The considerable amount of statistical data obtained by the author indicates that prevention of cracks and hair-lines should commence during melting and not after tapping. It has been found that both the duration of the boil as well as the rate of carbon elimination during this period influence the subsequent formation of cracks and hair-lines. The minimum cracking of blooms was obtained with a boil of about 2½ hr. The minimum number of defects was observed in metal from heats carried out at high temperature and with a normal rate of carbon elimination. A low rate of oxidation of the carbon and a low pouring temperature lead to increased cracking and hair-lines. The manganese content of the metal at the commencement of the boil should not be below 0·2%.

FORGING, STAMPING AND DRAWING

(Continued from pp. 84 A–85 A)

Stainless Forging Metals. W. Naujoks. (Metals and Alloys, 1939, vol. 10, May, pp. 144–150). The author discusses the various ferrous and non-ferrous metals and alloys which are both corrosion-resistant and suitable for the manufacture of drop forgings.

Savings Effected by Re-Forging Car Axles. C. Cleveland. (Heat Treating and Forging, 1939, vol. 25, May, pp. 221–223). The author describes the equipment and processes employed at the forging shop of the Chicago and North Western Railway, where scrapped railway truck axles are reforged and heat treated and made into the next smaller size of axle.

Ammunition Manufacture for the 3·7-inch Anti-Aircraft Gun. (Machinery, 1939, vol. 54, June 22, pp. 353–382). In this, the first of a series of articles, details are given of some of the operations in the manufacture of 3·7-in. shells for anti-aircraft guns. The account includes constructional features of the ammunition, production of the shell forgings, machining operations on the shell body, and manufacture of the cartridge cases.

Manufacture of Artillery Ammunition. L. H. Campbell, jun. (Iron Age, 1939, vol. 143, June, pp. 25–29, 69). The author describes the forging, heat treatment, machining, and fitting processes employed at the artillery ammunition department of Frankford Arsenal, Philadelphia, in the manufacture of shells.

The Manufacture of Shell Forgings by the Extrusion Process. (Machinery, 1939, vol. 54, July 6, pp. 433–435). A description is given of the process of making 3·45-in. high-explosive shells using a Duncan Stewart, 2000-ton, hydraulically-operated, extrusion press.

Investigations of the Flow of Material in Drop Forging. A. Pomp, T. Münker and W. Lueg. (Stahl und Eisen, 1939, vol. 59, June 1, pp. 649–661). The authors investigate the flow of metal and the power required to produce pressings and drop forgings. This is an abridged version of an article which appeared in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1938, vol. 20, No. 20, pp. 265–291. (*See* Journ. I. and S.I., 1939, No. I., p. 217 A).

Drop Forging of Steel and Light Alloys. (Metal Treatment, 1939, vol. 5, Summer issue, pp. 82–86). An abridged English translation of an account by K. Daeves and A. Ristow of an investigation of the drop-forging properties of 25 types of steel and 8 different light-metal alloys. The original article appeared in Stahl und Eisen, 1938, vol. 58, Dec. 22, pp. 1451–1457. (*See* Journ. I. and S.I., 1939, No. I., p. 152 A).

Cold Drawn Steel. S. A. Moht. (Iron Age, 1939, vol. 144, July 6, pp. 39–43). The author describes some of the steps taken in the reorganisation of a cold-drawing shop for steel bars and reproduces a number of charts showing the correction factor to be applied to the die diameter in order to produce the desired diameter of bar. These charts apply for bars $\frac{1}{4}$–2 in. in dia. of low-carbon and a number of alloy steels.

A Further Discussion of Reactive Wire Drawing. H. A. Stringfellow. (Wire and Wire Products, 1939, vol. 14, July, pp. 367–369, 395). The author replies to criticism of his previous article (*see* p. 85 A) on the theoretical considerations involved when a back-pull is exerted on wire passing through a drawing die. He stresses the point that, although in theory it would appear that the pressure on the die decreases directly with increasing back-tension, in actual practice it is found that as the back-tension is increased the amount of die pressure decreases at a slightly slower rate.

Calculation of Drawing Die Sets. P. Grodzinski. (Wire Industry, 1939, vol. 6, June, pp. 407–411). The author presents and explains some equations for the rapid calculation of lengths, die diameters and number of drawings for the production of specified quantities and sizes of wire.

The Carbide Die—History, Manufacture and Use. E. W. Engle. (Wire and Wire Products, 1939, vol. 14, June, pp. 319–324, 350–351). The author traces the history of the manufacture of the tungsten-carbide die for wire-drawing, giving several references to the literature. He discusses the factors influencing the die profile, the methods of fixing the die in its steel casing which gives it mechanical support, the grinding, polishing and lubrication of dies, and the causes of die failure. In conclusion he gives some statistics of the life and wear of dies used for drawing copper, brass and steel wire and tubes.

The Robertson High-Speed, Heavy-Duty, Non-Slip, Wire-Drawing Machine. (Wire Industry, 1939, vol. 6, July, p. 482). A brief illustrated description is given of a new wire-drawing machine having a wide range of speed which permits the drawing of mild steel, high-carbon steel, or nickel alloys at appropriate speeds with equal facility. A special feature concerning the die-cooling system is that dies may be removed instantaneously without breaking water connections or using tools.

ROLLING-MILL PRACTICE

(Continued from pp. 148 A–149 A)

Method of Calculating Roll Housings. P. Grüner. (Stahl und Eisen, 1939, vol. 59, July 20, pp. 833–840). The author explains the methods of determining the distribution of stresses at different positions in closed and open rolling-mill housings. His efforts to evolve a stand in which the stresses are evenly distributed resulted in new designs for a 2-high sheet-mill stand and for a 3-high stand.

Flood-Lubricated Sleeve Bearings for Rolling Mills. F. P. Peters. (Metals and Alloys, 1939, vol. 10, June, pp. 164–169, 196). The author describes the design and performance of the "Morgoil" bearing which is used for modern rolling-mill journals. This bearing consists of a sleeve of forged nickel-molybdenum steel keyed on to the roll-neck, and this sleeve rotates in a steel bushing lined with cadmium-nickel bearing metal. The bearing metal, known as "Asarcoloy," is centrifugally cast in place and its surface is accurately machined with a diamond tool. The bearing is flood-lubricated with oil at a pressure of 10–15 lb. per sq. in. from a central system. A bibliography of 17 references to the literature on rolling-mill bearings is appended.

The Use of Textolite Bearings on Sheet Mills. G. Vinogradov and G. Strepakov. (Stal, 1938, No. 11, pp. 58–61). (In Russian). The design, properties and life of the Textolite (fabric-reinforced synthetic resin) bearings used on the sheet mills of the Il'ich works are briefly described. Operating data indicate a definite connection between the bearing pressure and wear. The beneficial effect on the life of the bearings of the use of grease lubricants is emphasised.

Wisconsin Steel Works of International Harvester Company. (Iron and Coal Trades Review, 1939, vol. 138, June 16, pp. 1040–1041). An illustrated description is presented of the new 32-in. reversing blooming mill and the 21-in. six-stand continuous billet and bar mill recently put in operation at the Wisconsin Steel Works, South Chicago, of the International Harvester Co.

Continuous Mills—Suggestions for Increasing the Flexibility of Small Sections and Merchant Bar Mills. A. Musso, jun. (Iron Age, 1939, vol. 143, June 22, pp. 37–40). The author compares the advantages and disadvantages of a continuous mill with those of a 3-high hand and guide mill for the rolling of small sections and merchant bars. In view of the present difficulty of keeping a continuous mill working on large tonnages of one section, greater flexibility is desirable, and the author makes various suggestions,

such as means of reducing the time required to change rolls, driving the two rolls of a pair at slightly different speeds, the use of automatic devices for controlling rolling speeds, roll pressures and the tension between roll stands. The adoption of these practical proposals would, in the author's opinion, more than counterbalance the increased cost involved.

New 3-High Balanced Mill. (Iron Age, 1939, vol. 143, June, pp. 30–31). A description is given of the changes which were made in order to modernise a 2-high hand sheet mill at the works of The Continental Roll and Steel Foundry Co., East Chicago. A 3-high roughing mill is used for rolling sheet bars up to $\frac{9}{16}$ in. thick, and a new continental 3-high balanced mill is used for rolling $\frac{5}{8}$ in. to 2 in. sheet bars. Both mills are designed to produce an average of 1800 pairs of sheet bars in an 8-hr. shift.

Ebbw Vale Reawakes. Parts II. and III. (Iron and Steel, 1939, vol. 12, June, pp. 569–580; July, pp. 623–628). The description of the works of Richard Thomas and Co., Ltd., at Ebbw Vale is continued (*see* p. 77 A). In these two parts the rolling mills and the coke-oven and by-product plant are described and illustrated.

Tin Mill at the Irvin Works Modern in Every Respect. (Blast Furnace and Steel Plant, 1939, vol. 27, May, pp. 461–465). An illustrated description is presented of the new tinplate mill at the Irvin Works of the Carnegie-Illinois Steel Corporation which is designed for a production of 100,000 tons of tinplate per annum. The description covers the rolling mills, the electrolytic cleaning lines, the annealing department, the pickling equipment and the sorting and packing room.

The Forces Required for Rolling Steel Strip under Tension. A. Nadai. (Journal of Applied Mechanics, 1939, vol. 6, June, pp. A 54–A 62). In a mathematical discussion the author studies the influence on the roll pressures of applying front or back tension during the rolling of wide sheets. He also develops formulæ for calculating roll pressures when the surface friction is assumed to be constant and when it is assumed to be proportional to the relative velocity of slip.

The 76-in. Continuous Strip Mill of the Inland Steel Company. (Iron and Coal Trades Review, 1939, vol. 138, May 19, pp. 883–884). An illustrated description is given of the new 76-in. strip mill at the Indiana Harbor plant of the Inland Steel Co. This mill has a rated capacity of 50,000 tons per month and is designed for rolling plates $\frac{3}{16}$ in. to $\frac{3}{4}$ in. thick up to 72 in. wide, and strip 0·042 in. by 18 in. to 36 in. up to 0·076 in. by 74$\frac{1}{2}$ in.

Enlarges Cold Mill. (Steel, 1939, vol. 104, June 19, pp. 64–69). A brief illustrated description is given of the recently enlarged cold strip mill of the Superior Steel Corporation, Pittsburgh. The new plant includes a 4-high roughing mill and a 2-high finishing mill to roll strip up to 30 in. wide, and a continuous pickling plant with independently driven drums.

HEAT TREATMENT

(Continued from pp. 150 A–153 A)

Definitions for Steel Treatments. K. Daeves. (Metal Treatment, 1939, vol. 5, Summer issue, p. 72). An English translation is presented of some German definitions of terms and some proposals for further definitions relating to the heat treatment of steel. The original article appeared in Stahl und Eisen, 1938, vol. 58, Dec. 1, pp. 1369–1370.

Fuels for Heat-Treatment Furnaces. W. Ashcroft. (Metallurgia, 1939, vol. 20, June, pp. 57–58). The author discusses the advantages and disadvantages of electricity and of solid, liquid and gaseous fuels for heat-treatment furnaces.

British Standard Test Code for Fuel Fired Furnaces for Heating and Heat Treatment Purposes. (British Standards Institution, No. 859, 1939).

Liquid Bath Furnaces. (Industrial Heating, 1939, vol. 6, Jan., pp. 18–30; Feb., pp. 107–120). In the first two of this series of articles a number of oil, gas and electric furnaces used for heating salt and cyanide baths are described. Externally heated pot furnaces are dealt with in Part I., and internally heated furnaces are described in Part II.

Surface-Hardening and Hard-Surfacing. C. E. MacQuigg. (Welding Journal, 1939, vol. 18, June, pp. 341–348). The author describes in detail methods of surface-hardening steel using an oxy-acetylene flame, this being a form of heat treatment, and the application of welding to deposit a layer of hard alloy on steel. (*See* p. 90 A).

Scaling and Decarburisation of Carbon Steels. G. Bandel. (Metal Treatment, 1939, vol. 5, Summer issue, pp. 61–66, 71). An abridged English translation of the author's review of the literature up to 1937 on scaling and decarburising unalloyed steels which appeared in Stahl und Eisen, 1938, vol. 58, Nov. 10, pp. 1317–1326. (*See* Journ. I. and S.I., 1939, No. I., p. 100 A).

Protective Atmospheres and Bright Thermal Treatments. F. W. Haywood. (Metal Treatment, 1939, vol. 5, Summer issue, pp. 73–81, 98). The author reviews the present position of the application of controlled protective atmospheres for the bright annealing of ferrous and non-ferrous metals. He refers in particular to the properties and application of cracked ammonia and describes a patented " regenerative ammonia burner " unit in which the used nitrogen-hydrogen mixture contaminated with small amounts of oxygen and other impurities is regenerated by heating and passing

over suitable catalysts. Using one of these units the cost of the atmosphere has been reduced to about 9*d*. or 1*s*. per 1000 cu. ft. He also describes electric furnaces, the processes of descaling, clean or bright hardening, bright tempering and bright brazing.

" Artificial Water Load " Protects Direct-Fired Bright-Annealing Furnace Atmosphere During Low Production. (Industrial Heating, 1939, vol. 6, June, p. 512). A brief description is given of an auxiliary unit to a continuous bright-annealing furnace which increases the flexibility of production. The unit comprises a water-cooled tower through which part of the furnace gases may be drawn, cooled to room temperatures, and returned to the furnace, and its use enables the rate at which the work passes through the furnace during slack periods to be reduced without disturbing the pressure or temperature of the furnace atmosphere.

New Method of Constructing Air-Cooled Rollers for Annealing Furnaces Utilising the Air for Combustion Inside the Furnace. (Revue Technique Luxembourgeoise, 1939, vol. 31, May–June, pp. 69–73: Stahl und Eisen, 1939, vol. 59, June 29, pp. 753–756). A description is given of a new design of roller for moving the charge through an annealing furnace in which the cooling medium is air instead of water. As the heated air is passed to the gas burners and used for the combustion of the coke-oven gas, an improved thermal efficiency is obtained. This design of roller was introduced by P. Pfeffer.

Canadian Wire Mill Modernizes Its Annealing Department. L. D. Seymour. (Wire and Wire Products, 1939, vol. 14, July, pp. 370–371, 398). The author describes the annealing equipment recently installed at Hamilton, Ontario, by the Steel Co. of Canada. The plant consists of a cylindrical bell-type furnace heated by vertical radiant tubes, and four annealing covers over any one of which the furnace can be lowered. Each base and cover is provided with its own fan for circulating the gases, and the covers rest in an oil seal to prevent the inlet of air or moisture while cooling.

Lubrication in Heat-Using Industries. B. H. Porter. (Industrial Heating, 1939, vol. 6, June, pp. 491–494). The author describes several applications of graphite as a lubricant for use at high temperatures. A particular preparation which he mentions is an aqueous dispersion of colloidal graphite. The applications described include its use on dies in pressure die-casting, on bogies and chains used to move the charge in and out of large annealing furnaces, and for coating the threads of bolts and studs in steam and oil engines.

Normalising as a Means of Preventing Brittleness of Bessemer Steel Rails. V. Tikhovskiy, A. Zolotarev and N. Listovoy. (Stal, 1938, No. 21, pp. 58–61). (In Russian). Statistical data have shown that Bessemer steel rails tend to be more brittle than open-hearth steel rails. Tests on thirty heats of steel showed that rails with a high hardness due to their chemical composition were given a high ductility, considerably in excess of that required by standard

specification, by normalising. If the heating and cooling rates are correct, the hardness is not affected. The ductility is also favourably influenced by the use of hot-top moulds for teeming the ingots and by the development of inherent fine grain by the use of deoxidisers, in particular aluminium.

The Heat Treatment of Wire and Wire Products—Normalising Wire Rods. (Wire Industry, 1939, vol. 6, July, p. 506). Some criticism is advanced of A. T. Greiner's figures relating to the consumption of fuel oil in furnaces for annealing wire rod (*see* p. 92 A), it being shown that actually the cost is about 12½% higher than that previously stated. It is also pointed out that the rate of cooling of a mass of rods weighing, say, 6000 lb. must vary considerably throughout the mass. The rods at the centre will cool slowly and have an annealed structure, whilst the outer material will be normalised.

Tool Hardening. W. W. Young. (Heat Treatment and Forging, 1939, vol. 27, May, pp. 252–254). The author describes a number of small gas-fired furnaces with hearths up to 16 by 12 in. which he considers to be very suitable for small firms which do their own tool hardening. He also gives some operating data, such as the volume and calorific value of the heating gas, the time required to heat up to 1600° F., and the weight of steel which can be treated in 1 hr.

The High-Frequency Induction Hardening of Rail Ends. A. Makhanek. (Stal, 1938, No. 11, pp. 46–53). (In Russian). Results of tests on open-hearth and Bessemer steel rails, the heads of which had been hardened by the induction method developed by Vologdin, are described. Normal and transverse impact tests, and hardness tests and macro- and micro-structural examinations were carried out. The induction method can be used to harden the ends of rails to 300–400 Brinell, compressed air being used for quenching. The method can be used to give any required depth of hardening uniformly distributed longitudinally and latitudinally with a gradual transition to the unhardened metal. No overheating of the surface occurs. A pyrometer can be used to measure the temperature reached and the treatment can be completely automatic.

WELDING AND CUTTING

(Continued from pp. 154 A–155 A)

The Oxy-Acetylene Process Simplifies Steel Production. W. S. Walker. (Welding Journal, 1939, vol. 18, Apr., pp. 215–219). The author describes and illustrates some of the many applications of oxy-acetylene cutting and welding in a steelworks. These include cutting out surface defects from slabs, cutting up skulls with the oxygen lance, the maintenance of door frames of open-hearth furnaces, cutting profiles with a machine and welding repairs.

Welding in Chemical Engineering. (Engineering, 1939, vol. 147, June 16, pp. 705–709). A survey is presented of the many applications of welding in the manufacture of plant for the chemical industry. The electrical processes, such as automatic continuous arc-welding and flash butt-welding, are referred to chiefly, but the oxy-acetylene and oxy-hydrogen processes also have their special applications. The properties of welds made with bare and with coated electrodes are compared. Special reference is made to an austenitic stainless steel used for chemical plant construction which is known as " Silver Fox Twenty " ; this steel may be readily cold-worked and soldered, and it will deform to the same extent as deep-stamping steel. The approximate analysis of this steel is : carbon 0·08%, manganese 0·59%, silicon 0·60%, nickel 7·82% and chromium 18·0%. In plant built up of relatively thin sheets of this steel in which the welds cool rapidly, the steel is immune from inter-granular corrosion.

Forces Acting During the Transfer of Material Through the Welding Arc. J. Sack. (Welding Industry, 1939, vol. 7, July, pp. 234–240). The author analyses the forces which cause the transfer of metal from the electrode to the work in the electric welding process. The forces in question are gravity, surface tension, electrodynamic, and explosive. He illustrates his explanation with diagrams and X-ray cinema photographs.

Welds to be Carburized. E. J. Wellauer and G. C. Doehler. (Steel, 1939, vol. 104, June 4, pp. 58–61, 75). The authors report on an investigation which had the object of determining the most suitable type of welding electrode for making welds which were subsequently to be carburised. The steel which was welded was a forged and annealed S.A.E. 2315 steel containing 3½% of nickel. Four different kinds of electrode were tried and the specimens were carburised for 10 hr. at 1700° F. in a retort using a gaseous carburising medium. Hardness tests were made and the depths of case in both the weld and the parent metal were measured. They found that

there was least variation in hardness across the surface of the joint when an alloy-steel electrode was used. Joints made with a plain carbon-steel rod had too soft a case. A microscopic examination of the carburised metal revealed great differences in the structure of the parent and of the weld metal. Of the electrodes tested the carbon-molybdenum one produced a weld with the most nearly uniform properties.

Notes on the Welding of Low-Alloy High-Tensile Structural Steels. W. Barr. (Journal of the West of Scotland Iron and Steel Institute, 1939, vol. 46, Feb., pp. 83–87). The author discusses problems arising in the welding of high-tensile structural steel to British Standard Specification No. 548. This steel has a tensile strength of 37–43 tons per sq. in. and the carbon content must not exceed 0·3%. After explaining the theory of the hardening of steel by quenching, the author shows how the electric welding process affects the parent metal adjacent to the weld in a similar manner. He describes some laboratory tests on welded joints of high tensile steel using an electrode which deposits steel containing carbon 0·09%, silicon 0·15%, sulphur 0·025%, phosphorus 0·015%, manganese 0·50% and molybdenum 0·40%; this is a very suitable electrode for this work. He refers next to the influence of plate thickness and electrode gauge on the hardness and extent of the thermally affected area, and reproduces a number of micrographs which demonstrate clearly that the quenching effect of the surrounding metal increases with the plate thickness, and that the hardness of the boundary zones decreases as the gauge of the electrode increases. He concludes with a discussion on Swinden and Reeve's weld-cracking test and a brief description of two all-welded steel girders 120 ft. long.

Welding Galvanised Sheet. J. F. Galbraith. (Steel, 1939, vol. 104, June 12, pp. 50–51, 82). The author describes the technique to be employed for the welding of galvanised-iron vessels and tubes using either steel or bronze rods. He stresses the importance of not applying more heat than is necessary, so as to reduce the area of the galvanised coating which will be affected. In indoor work it is necessary to provide either some means of drawing off the zinc oxide fumes, or to supply the operator with a gas mask.

The Electric Welding of Copper-Plated Steel Sheet. W. Lessel. (Zeitschrift für Metallkunde, 1939, vol. 31, May, pp. 143–144). The author describes the correct technique to employ for the electric welding of copper-plated steel sheets and explains the causes of faulty joints which are sometimes produced.

Measurement of the Internal Stress of a Welded Piece by X-Rays. T. Nishihara and K. Kojima. (Transactions of the Society of Mechanical Engineers, Japan, 1939, vol. 5, Feb., pp. 159–162). (In Japanese). The authors report on their investigation by means of X-rays of the stresses set up in an electrically welded steel plate.

Developments in Thermal Stress Relief of Welded Structures. H. S. Card. (Industrial Heating, 1939, vol. 6, May, pp. 395–400;

June, pp. 496–506). The author discusses regulations laid down by some American societies and authorities regarding the stress-relieving of welded vessels and tubes; these are in general agreement that the correct normalising temperature is 1100–1200° F. He also describes and illustrates some very large furnaces which have been specially designed for the stress-relieving of large pressure vessels.

British Standard Nomenclature, Definitions and Symbols for Welding and Cutting. (British Standards Institution No. 499, Revised, June, 1939).

British Standard for Welded Steel Boilers for Steam Central Heating. (British Standard Institution, No. 854, 1939).

British Standard Specification for Welded Steel Boilers for Hot Water Central Heating and Hot Water Supply. (British Standard Specification, No. 855, 1939).

The Oxygen Lance Process. F. E. Rogers. (Welding Journal, 1939, vol. 18, June, pp. 352–356). The author describes the technique of cutting large masses of steel with the oxygen lance. In this process the cut is commenced either with an oxy-acetylene torch or with a few pieces of burning coal or cinder lying on the steel. The operator holds a long length of steel tube from $\frac{1}{8}$ in. to $\frac{3}{8}$ in. in dia., which is screwed at one end into a tube-holder which carries a quick-acting control valve. The tube-holder is connected to one or a battery of oxygen cylinders by a flexible pipe. The open end of the tube or lance is directed into the cut or on to the hot coal, and the oxygen is turned on at low pressure, which is gradually increased to 80–110 lb. per sq. in. Both the steel in front of the lance and the end of the lance itself burn away simultaneously; the operator feeds the lance forward until most of the length of tube has burned away, when he turns off the oxygen and quickly fits a new length of tube into the holder, turns on the oxygen and continues the process. The author gives particulars of the amount of steel displaced and burned, the length of pipe and the amount of oxygen consumed. The use of the lance for cutting up skulls and furnace bears, and for making holes in heavy crankshafts is illustrated and described.

Flame-Cutting Steel for Welding. E. D. Lacy. (Metal Treatment, 1939, vol. 5, Summer issue, pp. 67–71). The author describes some tests made on welded joints on $\frac{1}{2}$-in. steel plates, the edges of which had been prepared by cutting with the oxy-acetylene, the oxy-coal-gas flame, by shearing and by machining; the welds were made with flux-coated electrodes. Tensile, bend and notched bar impact tests were made, and there was no appreciable difference in the properties of the various specimens. This showed that there is no foundation for the theory that an oxide film is left by the flame, which has a deleterious effect on the weld. He also discusses the technique of hand and machine autogenous cutting, and describes some of the equipment used.

PROPERTIES AND TESTS

(Continued from pp. 163 A–172 A)

A New Universal Machine for Tensile, Compression and Bend Tests. R. Guillery. (Revue de Métallurgie, Mémoires, 1939, vol. 36, Apr., pp. 189–193). The author describes a new type of testing machine in which tensile, compressive and bend tests can be made. The power is supplied by an electric motor which drives two oil pumps, one with a rapid delivery for low-power tests and the other with a slow delivery for high-power tests. The machine is made in various capacities, and illustrations and diagrams of the 7-, 20- and 30-ton sizes are presented.

A Method of Presenting Flow Curves. J. de Lacombe. (Revue de Métallurgie, Mémoires, 1939, vol. 36, Apr., pp. 178–188). In this mathematical discussion the author explains his method of presenting and evaluating time-elongation curves plotted from the results of tensile tests on steel.

The Relation of Carbon Nodule Size and Tensile Properties of Malleable Cast Iron. H. A. Schwartz, H. J. Schindler and J. F. Elliott. (American Society for Testing Materials, 1939, Preprint No. 35). A given white cast iron was converted into malleable irons varying widely in nodule number. It is shown that a great variation in nodule number has little effect on the tensile strength and yield strength, but that a small nodule number is favourable to ductility.

Tensional Effects of Torsional Overstrain in Mild Steel. H. W. Swift. (Iron and Steel Institute, 1939, this Journal, pp. 181P–211P). This paper is concerned with the effects of initial torsional strain on the plastic stress-strain relationship and conditions of rupture of mild steel in tension. The conditions of rupture are discussed in the light of accepted facts; it is suggested that rupture in mild steel may occur either by tensile or by shear stress and that overstrain tends to weaken the metal in shear in a directional manner. Results are given of tensile tests on mild-steel bars previously subjected to various degrees of torsional overstrain. These results support the conclusions that the inception of plastic flow is affected by the internal stress system, that the subsequent plastic stress-strain relationship is affected, but only in its initial stages, by the previous strain history of the bar, and that the circumstances of ultimate rupture cannot in general be predicted in terms of any single one of the following conditions: tensile stress, shear stress, strain energy, hardness. The tests also show that the relationship between principal shear stress and shear strain under plastic conditions is not in-

dependent of the system of applied stress, nor is the resistance to further plastic strain controlled by either hardness or strain energy.

A Study of the Influence of Speed on the Torsion Impact Test. O. V. Greene and R. D. Stout. (American Society for Testing Materials, 1939, Preprint No. 108). This paper describes further experiments on the effect of velocity in torsion-impact testing of hardened 1·10% carbon tool steel. A range of speeds was investigated on the torsion impact and on a static torsion machine. As a part of the necessary information in the use of the static test, the modulus of torsion of hardened and drawn 1·10% carbon tool steel was determined. Data are presented to show that torsion-impact values are constant at the speeds investigated, and that both impact and static tests show the same shape of curve when the loads producing fracture are plotted against the drawing temperature. An explanation is offered for the disparity between fast and slow tests at drawing temperatures below 400° F. The results indicate that the torsion-impact test is essentially a rapid static test.

Stretcher-Strain Markings in Low Carbon Steel. J. D. Jevons. (Iron and Steel, 1939, vol. 12, May, pp. 425–430; July, pp. 629–635). The author examines the theories concerning the formation of stretcher-strain markings, or Lüders lines, in steel sheet and is of the opinion that: (1) These markings are the surface manifestation of localised, sharply defined, straight-sided, solid blocks or wedges of plastic deformation in the underlying sheet which appear at the upper yield point of annealed low-carbon steel and persist until the sheet has suffered a true elongation of about 4%, at which value the wedges increase in size and number and merge to a sheet free from non-plastically deformed areas. (2) This method of plastic deformation is attributable to a peculiar "lag" revealed on a stress-strain curve as a kink which annealed low-carbon steel exhibits at its yield point. (3) The wedges or markings are appreciably harder than the surrounding non-plastically deformed metal. (4) Except in very special instances, the surface markings are sunk beneath the normal surface level of the sheet. In the second part he critically examines the "lag" hypothesis mentioned in (2) and Kuroda's "honeycomb" hypothesis, according to which the fact that neither ferrite nor cementite has a yield-point elongation has its origin in a special structure composed of ferrite crystals surrounded by envelopes of cementite. In conclusion the author deals with methods of preventing the formation of stretcher-strain markings. In regard to the influence of the oxygen content of the steel, he explains that this has an indirect effect, in that it increases the ageing properties of low-carbon steel in the sense that the higher the oxygen content, the more quickly the effects of preventative treatments, such as temper-rolling, pass off.

Factors Influencing the Failure of Naval Boiler Tubes. A. P. Calvert. (Journal of the American Society of Naval Engineers, 1939, vol. 51, Feb., pp. 1–33). Commencing his paper with a list

of the principal possible reasons for boiler-tube failures classified under those influenced by (1) design, (2) material and/or construction and (3) operation, the author proceeds to review briefly the metallurgy of boiler-tube steel and discusses the results of hardness surveys carried out at the American Naval Engineering Experiment Station on parts of boiler tubes which have failed. The author is of the opinion that fractures characterised by thick lips of metal are the result of pulsating or intermittent circulation over an appreciable length of time sufficient to allow the tube metal to become heated to temperatures above 1000° F., at which creep of the tube material takes place. The other type of failure characterised by knife-edged lips he believes to be the result of an operating condition in which the tube becomes steam-bound in its upper reaches, thus allowing the temperature of the tube to rise well above its upper critical temperature and remain there until a blister forms, which subsequently bursts. The author also presents a comprehensive review of the results of many investigations of boiler-tube failures carried out at the experiment station previously mentioned, and correlates these results with information obtained from other sources.

Fatigue of Metals—Developments in the United States. H. F. Moore. (Metals and Alloys, 1939, vol. 10, May, pp. 158–162; June, pp. 180–183). After mentioning that the Research Committee of the American Society for Testing Materials feels that it would not be wise at this stage to adopt a rigid standardisation of definitions relating to fatigue testing, the author discusses the principles of several types of fatigue-testing machines and the preparation of specimens. He also considers the present trend of investigations of the fatigue strength of steel, and suggests that the effect of a crack on the wave form or on the damping of vibrations in the metal may provide a more sensitive means of detecting the early stage of development of a fatigue crack than any of the present methods. The author appends a bibliography of 27 references to the American literature.

Fatigue Strength of Machined Forgings 6 to 7 in. in Diameter. O. J. Horger and H. R. Neifert. (American Society for Testing Materials, 1939, Preprint No. 39). The Association of American Railroads is making extensive laboratory tests to determine the fatigue strength of full-size railway truck axles, and this paper forms a progress report on some of this work. Rotating cantilever-beam fatigue tests made on tapered machined specimens from thirty-one steel forgings from the same heat of S.A.E. 1045 steel are discussed. These specimens were tested in the as-forged condition without heat treatment, but machined after forging to produce a smooth surface. Data are included on reduced scale fatigue tests of 1·5 and 0·3 in.-in-dia. specimens. Metallurgical studies and profilograph records of surface finish supplement the fatigue tests. A discussion of test results with reference to those of previous investigators is also given.

Fatigue Tests of Wire. C. P. Wampler and N. J. Alleman. (American Society for Testing Materials, 1939, Preprint No. 40). In many applications the serviceable life of wire is terminated by fatigue failure. Testing machines necessitating a machined specimen do not give a true index of the endurance properties of wire, because the effects of surface conditions are removed. In this paper a method is presented for testing straight wire with the original surface intact, and a correlation of the results, using a bridge wire and a low-carbon steel, is obtained on a second type of testing machine. The two types of wire-testing machines are described, as well as the machine for testing machined specimens. The results of testing a low-carbon steel rod and a brass rod indicate that a permanent elongation of 0·10%, which is sufficient to straighten some coiled wire, does not appreciably influence the endurance limit.

An X-Ray Study of the Changes that Occur in Malleable Iron During the Process of Fatiguing. R. G. Spencer. (Physical Review, 1939, vol. 55, June 1, pp. 991–994). The author describes an X-ray investigation of the changes which occur in specimens of malleable iron while subjected to fatigue tests. The tests were carried out in an ordinary rotating-beam machine, from which the specimen was removed at intervals so that X-ray diffraction patterns could be obtained. He found that when the stress applied was below the endurance limit, no changes in internal structure were detectable by the camera used after the first few cycles. When a stress above the endurance limit is applied, appreciable changes may take place during the first few cycles and further changes take place comparatively slowly during the major part of the test. These changes proceed at an accelerated rate as the specimen approaches fracture. The changes consist of (*a*) rotation of some of the grains, (*b*) introduction of strains in some of the grains, and (*c*) fragmentation of some of the grains into sizes so small that these are randomly orientated.

Fatigue Machines for Testing Structural Units. R. L. Templin. (American Society for Testing Materials, 1939, Preprint No. 41). Fatigue tests of structural units such as joints, beams, columns and frames carried out under normal working loads will give results which should be of considerable assistance in improving the design of such structural units, so as better to withstand repeated service loads. This paper describes in some detail three types of relatively large fatigue-testing machines which have been designed for the purpose mentioned above. The functioning and calibration of the machines are discussed in some detail, and the results obtained from four years' use are briefly indicated. A limited amount of test data is included.

Fatigue of Boiler-Plate Iron. N. N. Afanas'ev. (Vestnik Metallopromyshlennosti, 1939, No. 3, pp. 28–34). (In Russian). Flat plate test-pieces of 0·15% carbon boiler-plate iron were used to determine the fatigue strength of the metal. Data are presented for the fatigue strength, in bending, of the material at 20° and

350° C. Test pieces with holes, after cold working and after ageing treatments, were also tested to determine the effect of these factors on the fatigue strength.

Analysis of Rockwell Hardness Data. R. L. Peek, jun., and W. E. Ingerson. (American Society for Testing Materials, 1939, Preprint No. 106). The authors analyse Rockwell hardness test results (*a*) to correlate readings made with different loads and ball diameters, and (*b*) to simplify the relation between hardness and tensile-strength measurements. From their analysis they consider that it should be possible to calibrate a Rockwell testing machine using a single test-block and taking readings with various loads, instead of having to use a different block for each point to be checked in the calibration. They develop an equation which should enable hardness limits to be included in specifications which would correspond to limits of tensile strength.

Rockwell Hardness of Cylindrical Specimens. W. E. Ingerson. (American Society for Testing Materials, 1939, Preprint No. 107). A theoretical method for correcting the apparent Rockwell hardness numbers obtained on cylindrical specimens using the ball penetrator is developed. The deviation of the apparent from the true hardness is found to vary approximately linearly with the depth of impression for a given specimen diameter. It has been calculated for various specimen diameters from $\frac{1}{8}$ in. to 1 in. Experimental results of tests on specimens from $\frac{1}{8}$ in. to 1 in. in diameter of various materials, using the Rockwell "B," "F," and "G" scales are presented. Correction curves are presented by using which the true Rockwell hardness, on the "B," "F," and "G" scales can be obtained from measurements made on cylindrical surfaces.

The Resistance of High-Silicon Malleable Iron to Drilling. H. A. Schwartz, R. C. Kasper and N. E. Mertz. (American Society for Testing Materials, 1939, No. 36). The machinability of malleable cast iron containing 2·09% to 2·36% of carbon and 1·39% to 2·10% of silicon has been determined in the Olsen Efficiency Machine by drilling, and it is shown that both carbon and silicon improve the machinability of malleable iron as measured by the rate of penetration of a standard drill, or by the torque on a drill running with a predetermined advance per revolution. Silicon is about twice as effective as carbon in reducing the torque.

A Further Investigation of the Time-Lag in the Magnetisation in the Upper and in the Steep Portions of the Hysteresis Loop. J. Ôkubo and N. Yamanaka. (Science Reports of the Tôhoku Imperial University, 1939, vol. 27, Apr., pp. 429–449). The authors report on their further investigations of the transient process of magnetic induction in Armco iron, electrolytic iron and electrolytic nickel in the upper and the steep portions of the hysteresis loop. (For previous report *see* Journ. I. and S.I., 1936, No. II., p. 262 A). They find that the magnetic permeability of these materials in the observed ranges of the changes of field remain at an almost constant

value. They show that the time-lag in the upper portion of the loop is in good agreement with Wivendensky-Kiessling's theory of eddy currents, whilst that in the steep portion is much greater than that expected from this theory.

On the Longitudinal Magneto-Resistance Effect at Various Temperatures in Iron-Nickel Alloys. Y. Shirakawa. (Science Reports of the Tôhoku Imperial University, 1939, vol. 27, Apr., pp. 485–560). The author reports the results obtained from an investigation of the changes in magnetic resistance of iron-nickel alloys in the temperature range — 195° to + 850° C. up to 1600 oersted in longitudinal magnetic fields.

On the Longitudinal Magneto-Resistance Effect at Various Temperatures in Iron-Cobalt Alloys. Y. Shirakawa. (Science Reports of the Tôhoku Imperial University, 1939, vol. 27, Apr., pp. 532–560). The author reports the results of magnetic-resistance determinations of iron-cobalt alloys at temperatures in the range — 195° to + 1150° C. up to 1600 oersted in longitudinal magnetic fields.

Internal Strains and Magnetism. R. Becker. (Proceedings of the Physical Society, 1939, vol. 51, Part 5, No. 287). The author presents methods of calculating the internal stress of a metal from its magnetic properties.

The Inner, Initial, Magnetic Permeability of Iron and Nickel at Ultra-High Radiofrequencies. J. L. Glathart. (Physical Review, 1939, vol. 55, pp. 833–838). The author describes a new method for the measurement of the initial, inner, magnetic permeability of ferro-magnetic materials at ultra-high frequencies. This method has much greater accuracy and can be carried out much more rapidly than former methods. The probable error is less than 1% at a frequency of 197 megacycles per sec. By this method the author found the magnetic permeability of high-purity, commercial iron wire to be $53{\cdot}8 \pm 0{\cdot}3$ at $1{\cdot}97 \times 10^8$ cycles per sec. at 25° C. It was constant for all values of tension up to the breaking point of the wire, and it remained constant for all values of tension for superimposed longitudinal magnetic fields up to 100 oersted.

The Alloy Casting Research Institute Test-Block for Heat-Resisting Alloys; Its History, Selection and Utilization. O. E. Harder. (American Society for Testing Materials, 1939, Preprint No. 29). The author reviews a survey conducted by the Battelle Memorial Institute to determine the opinion of American foundries and testing laboratories regarding the most suitable type of test specimens of heat-resisting alloys for the determination of tensile strength and creep characteristics at high temperatures. He describes a wedge-shaped test block with a riser along the entire length but gated only at the bottom, which was developed by the above institute, and discusses the investigation which the Alloy Casting Research Institute carried out on a number of different

test-blocks, in which the ease of casting, soundness and mechanical properties of specimens, and the amounts of metal melted to produce a given number of specimens are compared.

The Creep of Metals. D. Hanson. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1071 : Metals Technology, 1939, vol. 6, June). In the first part of this paper the author studies the factors influencing the creep of metals and the relation between them, and in the second part he considers the metallographic aspect of creep. Referring to the fact that very different results are often obtained by different investigators of creep when using similar materials, the author believes that this is an indication of the fact that the creep characteristics of a metal are influenced profoundly by factors that are comparatively unimportant in relation to mechanical properties at low temperatures.

Selective Tests on High-Temperature Heat-Resisting Steels. N. Minkevich and A. M. Borzdyka. (Metallurg, 1939, No. 1, pp. 61–78). (In Russian). The following groups of steels were tested with a view to selecting suitable alloys for service at 800–1000° C. :

I. Austenitic chromium-nickel-base steels

	C. %.	Si. %.	Mn. %.	Ni. %.	Cr. %.	W. %.	Mo. %.
Steel (*a*) . .	0·55	0·75	0·64	15·1	14·2	2·4	0·41
Steel (*b*) . .	0·40	1·50	0·50	13·0	12·9	11·2	...

II. Austenitic, or nearly austenitic, chromium-manganese-base steels

	C. %.	Si. %.	Mn. %.	Cr. %.	W. %.	Ti. %.
Steel (*c*) . .	0·38	1·8	12·2	14·7	2·2	...
Steel (*d*) . .	0·41	1·65	13·6	14·1	3·1	...
Steel (*e*) . .	0·51	2·3	15·2	13·8	...	2·6

III. Pearlitic, carbide-bearing, chromium-base steels

	C. %.	Si. %.	Mn. %.	Cr. %.	W. %.	V. %.	Mo. %.
Steel (*f*) . .	0·47	1·8	0·5	9·2	3–4	0·75	...
Steel (*g*) . .	0·50	1·40	0·5	8·6	...	...	2·25

The behaviour of these steels at elevated temperatures was first studied by dilatometric and hardness measurements and under the microscope, and the structural changes which occurred are discussed. These preliminary experiments were followed by scaling tests, short-time tensile tests at 20°, 800° and 1000° C., impact tests at the same temperatures, tests on the development of brittleness on heating at 600° and 800° C. for up to 120 hr. and finally, by creep tests at 800° and 900° C. (10^{-4}% elongation per hr. between the twenty-fourth and forty-eighth hours). The results of the short-time tensile tests and the creep tests enable the steels to be divided into two groups : those resistant to high temperatures and those resistant to low temperatures. Steels (*a*), (*b*), (*c*), and (*d*) were found to belong to the former, and steels (*e*), (*f*), and (*g*)

to the latter group. Steels of the first group differ but slightly among themselves, steels (*a*) and (*c*) being the best. At 800° C. the steels of the first group differ from those of the second much more in short-time tensile strength (differences of 200–250%) than in creep strength (differences of 25–35%). These differences were much less at 900–1000° C. Steel (*e*) was shown by all the tests to have the lowest heat-resistance.

Heat- and Corrosion-Resistant Castings of the Chromium-Nickel-Iron Types. J. D. Corfield. (American Foundrymen's Association, May, 1939, Preprint No. 30). The author surveys from the foundryman's point of view the properties of heat- and corrosion-resisting cast irons containing nickel and chromium.

Spectral Emissivity (at 0·65 μ) of Some Alloys for Electrical Heating Elements. W. F. Roeser. (American Society for Testing Materials, 1939, Preprint No. 43). Determinations of the spectral emissivity of a number of commercial heating-element materials were made to obtain data needed for the measurement of the operating temperature of these alloys during life tests. The spectral emissivity of the alloys was determined both in air and under conditions which are ordinarily considered to be reducing, by measuring the true temperature and the apparent temperature of the surface at the effective wave-length (about 0·65 μ) ordinarily used in optical pyrometry. The emissivity of the oxide or oxides formed on each general class of material in air was apparently definite and characteristic of that class of material. In commercial hydrogen, each of the alloys studied acquired a coating of oxide which differed in radiation characteristics from that formed in air at high temperatures. The emissivity of the oxide formed on the nickel-chromium and nickel-chromium-iron alloys in commercial hydrogen varied between wide limits (about 0·4–0·85) depending upon the atmosphere and the conditions of heating. The emissivity of the nickel-chromium and nickel-chromium-iron alloys in an atmosphere of hydrogen sufficiently pure to prevent the formation of any oxide was about 0·35. Although an atmosphere was not obtained which would prevent the formation of an oxide on the iron-chromium alloys containing aluminium, the results obtained on iron-chromium alloys containing various amounts of other elements indicate that the emissivity of the iron-chromium-aluminium alloys would not differ appreciably from 0·35 if these alloys could be heated in the absence of any oxygen.

Sub-Size Charpy Relationships at Sub-Zero Temperatures. H. Habart and W. J. Herge. (American Society for Testing Materials, 1939, Preprint No. 37). Charpy impact tests were made on eight steels at 70° F. and sub-zero temperatures down to −150° F. Standard and various sub-size specimens were broken at each testing temperature. In most cases the impact resistance of ferritic steels, as measured on standard and two-thirds full-size specimens, decreased when the testing temperature was decreased. Half-

size specimens also decreased in impact resistance, but not in the same marked degree as larger-size specimens. Smaller specimens have practically constant impact resistance throughout the temperature range used. The impact resistance of an austenitic 18/8 chromium-nickel steel increased with decreasing temperature. The results of the tests are summarised to show relationships between small specimens and standard-size specimens at each testing temperature. A table of working values for relationship between the various specimen sizes at each testing is included.

Mechanical Properties of Rolled Steel St-3 at Low Temperatures. I. V. Kudryavtsev. (Vestnik Metallopromyshlennosti, 1939, No. 3, pp. 6–15). (In Russian). The Bessemer and open-hearth steel joists investigated ranged in composition as follows: Carbon 0·06–0·23%, manganese 0·30–0·61%, sulphur 0·029–0·062%, phosphorus 0·027–0·084%, nitrogen 0·005–0·014%, and oxygen, 0·0060–0·02450%. Mechanical tests (tensile, bending, hardness and impact) were carried out at room temperature and at temperatures down to − 70° C. Normalising was found to have very little effect on the falling-off in properties at low temperatures. Open-hearth steel was the least affected by strain ageing. The superiority of one batch of clean steel low in sulphur, phosphorus, nitrogen and oxygen was particularly marked.

Properties of Nickel Alloy Steels at Low Temperatures. M. Yamaguchi. (Japan Nickel Information Bureau, 1939, Technical Information B-3). The author reviews under the following headings the present state of knowledge concerning the properties of nickel steels at low temperatures: (1) Low-temperature brittleness of metals and mechanism of occurrence of brittleness; (2) effect of low temperature upon properties of ordinary carbon steel; (3) structural nickel alloy steels at low temperatures; (4) high nickel steels at low temperatures; (5) stainless steels at low temperatures; and (6) effect of temperature on properties other than impact resistance.

Cast Iron in Engineering Construction. J. L. Francis. (Iron and Steel, 1939, vol. 12, Mar., pp. 337–340; May, pp. 435–440; June, pp. 581–587). Continuation of a series of articles. (*See* Journ. I. and S. I., 1939, No. I., p. 236 A). In Part IX. of this series the author reviews some of the earlier processes of controlling the carbon content and modifying the size of the graphite in cast iron. From this he proceeds to discuss inoculated irons with particular reference to the Meehan process developed in the United States by O. Smalley; in this the inoculant used is carbon-free calcium silicide, which is added to the metal stream as it flows from the cupola spout. The theory of the inoculation process is that finely dispersed graphite formations will result in the melt if the nuclei upon which initial deposition takes place are more or less absent from the charge components but are added in controlled amounts just prior to casting. This method of production allows a wide

range of modification, and five grades have been standardised in accordance with the tensile strength of the product. Grade *A* has a tensile strength of 20–23 tons per sq. in. and a Brinell hardness of 200. The tensile strengths of the remaining grades are : *B* 18½–20 tons, *C* 17–18 tons, *D* 15–16 tons and *E* 14–15 tons, all per sq. in. Grade *E* is regarded as the common or general-purpose foundry iron. The author concludes this part with an account of the production of Ni-Tensyl iron in which the inoculant is a mixture of nickel and ferro-silicon. In Part X. the author deals with the production and properties of low-alloy cast irons. To obtain the maximum results from any alloy additions it is usual to adjust the silicon content to suit the amount of alloy added. Taking the effect of silicon on graphitisation as unity, the effect of some of the alloying elements is as follows : Aluminium 0·5, copper 0·35, nickel 0·33, manganese −0·25, molybdenum −0·35 and chromium −1·2. A negative value indicates that the alloy has a chilling tendency. The author discusses in particular the effects of nickel and chromium additions on the properties of cast iron in this part. In Part XI. the author deals with the effect of additions of molybdenum, copper, copper and chromium, titanium and aluminium on the properties of cast iron, and with the production and properties of supercooled iron with a graphite structure.

Engineering Properties of Gray Iron Improve. V. H. Schnee and C. H. Lorig. (Foundry, 1939, vol. 67, May, pp. 40–42, 86, 89). The authors review recent technical literature on the development of high-duty cast irons. A bibliography with ninety-one references to papers published in 1938 is appended.

Mechanical Properties of a High-Strength Cast Iron. J. A. Draffin and W. L. Collins. (American Society for Testing Materials, 1939, Preprint No. 33). This paper presents the results of tests on a high-strength cast iron. The tests are very similar to those of a low-strength iron presented before the Society in 1937 and 1938, wherever feasible comparisons between the two types of iron are made. Tests were made : (1) in tension, on solid and hollow specimens ; (2) in compression, with specimens having length/diameter ratios of 3 and 6 ; (3) in torsion, with solid specimens ¾ in. and 1 in. in dia. and with hollow specimens of various wall thicknesses ; (4) by repeated stress in completely reversed torsion with and without a hole ; and (5) by the bending of solid rectangular and I-beams. Strain readings were taken on nearly all specimens except those tested under repeated torsion. Measurements were made to determine Poisson's ratio for the top and bottom of each beam.

Cobalt- and Cerium-Bearing Irons. L. Guillet. (Chimie et Industrie, 1939, vol. 41, May, pp. 853–860). In the first part the author studies the influence of the effect of additions of 0·05% to 3·46% of cobalt on the structure and properties of two qualities of cast iron containing carbon 3·55% and 3·37%, and silicon 1·51% and 0·97%, respectively. In general, additions of cobalt slightly

assist the formation of graphite on cooling and lower the temperature at which graphitisation commences. It dissolves in the ferrite and slightly increases the resistance of the iron to attack by weak acids. It lowers all the mechanical properties of the iron rapidly at first, but more slowly as the amount added is increased. In the second part he examines the effect of the presence of traces of cerium on cast iron, and finds that it strongly opposes the formation of graphite, and consequently whitens the fracture; it also retards the rate of decomposition of the cementite on annealing.

The Properties of Titanium- and of Boron-Bearing Iron. P. Bastien. (Chimie et Industrie, 1939, vol. 41, May, pp. 835–852). In the first part of his paper the author discusses the effects of additions of titanium on the properties of cast iron, and as a result of his experiments he concludes that: (1) Titanium acts as a graphitiser, and, within the range of his own experiments, it does not affect the temperature of the commencement of graphitisation, but it increases the linear expansion of the iron. (2) It has a marked effect on the size and distribution of the graphite during solidification. The fact that it reduces the size of the graphite particles makes titanium-bearing iron suitable for abrasion- and heat-resisting purposes. (3) It is probable that titanium does not enter into solid solution in cementite and only slightly in ferrite. (4) Mechanical tests show that very small additions of titanium cause a sharp fall in the strength of cast iron, but after a critical amount (about 0·09–0·15%, depending on the amount of carbon) the strength recovers and increases beyond the original value. In the second part the author deals with the effect of boron, and his conclusions are: (1) Boron tends to prevent graphitisation, and therefore whitens the iron. (2) It decreases the rate of decomposition of the cementite. (3) Increasing quantities of boron raise rapidly and steadily the temperature of the cementite A_0 anomaly. (4) The addition of boron increases the mechanical strength of cast iron, but decreases its ductility.

British Standard Specification for Wrought Iron for General Engineering Purposes (Grades A, B and C). (British Standards Institution No. 51, Revised June, 1939). This specification retains grades A, B and C wrought iron, but instead of being restricted to use for railway purposes, as in the previous specification, their use is now extended to general engineering purposes. The mechanical properties and test requirements of the three grades have not been modified, but the methods of making the tests have been recast in a form which it is hoped will prove to be more explicit, and so render the specification more useful.

British Standard Specification for "Best Yorkshire" Wrought Iron. (British Standards Institution No. 858, 1939). The term "Best Yorkshire" originated from the name of the district in which this quality of puddled wrought iron was first produced. The term is so well established that any other description would be liable to mislead, but no geographical limitation or proprietary right is im-

plied by its use. With regard to chemical composition, it is stipulated that the manganese and phosphorus shall not exceed 0·06% and 0·16%, respectively. The rolling margins, methods of testing, and the physical properties are all specified.

What the Engineer Should Know about Steel. W. H. Hatfield. (Journal of the Institution of Production Engineers, 1939, vol. 18, June, pp. 235–248). The author commences with an explanation of the mechanism of hardening steel and explains how this mechanism is affected by the addition of alloying elements. He answers the question "When should we use alloy steel and when carbon steel?" by referring to the cost and to the necessity of saving weight, and quotes the example of the aeroplane engine as an instance of the advantageous use of alloy steels. He deals next with inclusions in steel, and describes with diagrams what happens during the solidification of a steel ingot. In conclusion, he considers the effect of the grain size on the mechanical properties of steel, and in this connection describes an experiment on two bars of 0·45% carbon steel 6 in. sq. on which longitudinal and transverse tensile tests were made. The results showed that the addition of aluminium, although producing a small grain size, also produced a great number of inclusions which, during the rolling, aligned themselves in the direction of the bar and substantially decreased the transverse ductility of the material.

Low-Carbon Steels with Increased Strength. K. Antipov. (Stal, 1938, No. 12, pp. 56–58). (In Russian). Test data on a series of low-carbon steels with small alloy additions are given and briefly discussed. Tensile, bend and impact tests showed that very good properties were possessed by basic open-hearth steels of the following compositions:

	(1) %	(2) %	(3) %	(4) %	(5) %
Carbon	0·14	0·15	0·18	0·09	0·12
Silicon	1·02	0·79	0·64	0·80	1·03
Manganese	0·48	0·5	0·73	0·67	0·35
Chromium	0·90	1·11	0·69	0·74	1·03
Copper	0·39	0·58	...	0·58	0·36
Phosphorus	0·021	0·154	0·034	0·145	0·114
Sulphur	0·016	0·012	0·014	0·024	0·020
Nickel	...	0·10	...	0·57	0·09

Steels (2) and (5) were found to be particularly suitable for sheet making.

Improving the Physico-Mechanical Properties of Low Carbon Steel. N. F. Lashko and G. Ya. Slobodyanyuk. (Metallurg, 1939, No. 2, pp. 64–70). (In Russian). Impact tests on test pieces cut from 0·05–0·06%-carbon basic-Bessemer steel angles and from bars of a 0·12%-carbon open-hearth steel showed that in the normalised state (normalised at 950° C.) cold brittleness developed at temperatures of 0° to − 5° C. After quenching from 900° C., this cold-brittleness temperature was lowered in the case of the Bessemer

steel to − 70° to − 80° C. The force required to fracture also increased from 10–12 kg./m. to 40 kg./m. and greater. Subsequent tempering had little effect. Quenching of the 0·12%-carbon open-hearth steel, on the other hand, raised the cold-brittleness temperature to + 15° C.

Antimony in Mild Steel. B. Jones and J. D. D. Morgan. (Iron and Steel Institute, 1939, this Journal, pp. 115P–136P). The authors refer to the lack of information on the effects of certain elements on steel. Experiments are described in this paper on the effects of increasing the antimony content in a 0·17%-carbon steel. A complete investigation was not attempted, but the influence of the element on some of the useful properties of the steel was examined. Twelve steels of basic electric origin and four high-frequency steels were tested. Antimony has practically no effect on the A_1 point, but progressively raises the A_3 temperature of steel owing to its stabilising effect on α-iron. The microstructures found have been correlated with the iron-antimony equilibrium diagram. Steels containing up to 0·69% of antimony can be hot-forged and hot-rolled, but with higher antimony contents the steels become increasingly red-short. Antimony has practically no effect on the tensile strength, while increasing amounts rapidly decrease the maximum stress to very low values. As with other elements in group VB of the Periodic Table forming γ loops with iron, such as phosphorus and arsenic, antimony embrittles steel, low notched-bar impact values being found in steel containing more than approximately 0·5% of the element. The influence of antimony on case-hardening processes has been examined. Small amounts of antimony were found to make steel slightly more susceptible to atmospheric corrosion and acid attack. Steels with increasing amounts of antimony become more resistant. Above 0·5% of antimony the steels resist attack by 5% and 25% sulphuric acid at 25° C. to an increasing extent, and to a less degree by hydrochloric acid of the same strengths. Antimony-cemented steel is highly resistant to atmospheric and acid attack.

The Effect of Some Special Elements on the Properties of the Chromium-Silicon-Vanadium Steel Used as a Substitute for High-Speed Steel. N. T. Gudtsov, A. N. Bekova, S. A. Kazeev and A. Polyakov. (Metallurg, 1939, No. 1, pp. 51–61). (In Russian). The authors investigate the effect of small additions of niobium, tantalum, titanium, cobalt and molybdenum on the properties of chromium-silicon-vanadium tool steel *E*1172, and describe the melting of the steel in a high-frequency furnace, the casting, the microstructure, the forging and the annealing. In determining the optimum quenching and tempering treatments, variations in hardness and structure of the steels were taken into account. Finally tests were made to determine the life of the various steels when cutting forged carbon steel. The results showed that additions of molybdenum and titanium are particularly beneficial, and a steel of the following composition is recommended: 1–1·2% of carbon,

0·9–1·6% of silicon, 2–2·5% of vanadium, 10–13% of chromium, and 3–4% of molybdenum. It is claimed that as regards machining capacity, this steel is equivalent to high-speed (tungsten) tool steel. The molybdenum may be replaced by 0·3–0·4% of titanium with only a slight falling-off in the cutting properties.

The Effect of Alloying Elements on the Mechanical Properties of Chromium-Nickel-Tungsten Structural Steel 25*KhNVA* (*E* 18) and 18*KhNVA* (*E* 16). V. M. Doronin. (Metallurg, 1939, No. 2, pp. 56–65). (In Russian). Steel 25*KhNVA* has the following specified composition: Carbon 0·20–0·30%, chromium 1·35–1·65%, nickel 4·10–4·60%, tungsten 0·80–1·20%, silicon 0·17–0·37%, manganese 0·25–0·55%, phosphorus $\leqslant$0·035%, and sulphur $\leqslant$0·030%, whilst the carbon content of steel 18*KhNVA* is slightly lower at 0·15–0·22%. In the present article the results of statistical analyses of test data for 486 tests (about 2300 test-pieces) of 25*KhNVA* and 970 heats (about 7700 test-pieces) of 18*KhNVA* are described and discussed. The object of these investigations was to determine the effect of varying each of the alloying elements within the above limits on the tensile properties, impact strength, and hardness of the steels, as well as to determine the optimum heat-treatment temperatures. Increasing the carbon, phosphorus and silicon raise the tensile strength, but lower the ductility, whilst chromium, nickel, tungsten, and manganese raise both the tensile strength and ductility. Carbon has the greatest effect on the optimum tempering temperature (the tempering temperature is raised 4° C. per 0·01% of carbon), followed by phosphorus (3° C. rise per 0·01%), tungsten (2° C. rise per 0·1%), chromium (2° C. rise per 0·1%), and nickel (1·5° C. rise per 0·1%). Silicon and manganese in the amounts present had no noticeable effect. The results obtained in the investigation enable the mechanical properties of any heat to be calculated from its chemical composition.

Chromium in Structural Steel. W. Crafts. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1055 : Metals Technology, 1939, vol. 6, June). The author outlines the more significant properties of chromium-bearing structural steel, and points out that the addition of chromium has a remarkable toughening effect, especially when the steel has a high phosphorus content. He compares the influence of chromium with that of other alloying elements, and from this comparison concludes that although chromium is essential only in some types, such as high-phosphorus steels, it is desirable to include it in almost all alloy steels.

Manganese-Vanadium Steel for Forgings. (Alloy Metals Review, 1939, vol. 2, June, pp. 65–68). Some details are given of the physical properties of manganese-vanadium steels, which are being increasingly used for reciprocating parts in American locomotives. The steel contains manganese 1·45–1·75% and vanadium 0·15% min. Special reference is made to its properties after quenching in water and tempering.

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 173 A–177 A)

Metallurgical Nomenclature. P. W. Priestley. (Journal of the Institute of Automobile Assessors, 1939, vol. 1, July, pp. 50–63). The author presents a comprehensive list in alphabetical order of metallurgical terms and their meanings.

Advances in Microscopy. (Metallurgist, 1939, vol. 12, June, pp. 42–44). In this article attention is drawn to some recent advances in the art of microscopy, with particular reference to the electron microscope and its application to the study of metals.

The Electrolytic Polishing of Iron and Steel. (Metallurgist, 1939, vol. 12, June, p. 39). An electrolytic method of polishing copper, aluminium and tin has now been extended by P. Jacquet and P. Rocquet to the polishing of iron and steel for microscopic examination. The electrolyte is prepared by pouring slowly, a little at a time, 765 c.c. of pure acetic anhydride into a cooled vessel containing 185 c.c. of 65% perchloric acid (density 1·61), and then adding 50 c.c. of distilled water. The specimen forms the anode and the cathode may be a plate of iron or aluminium. The current density should be between 4 and 6 amp. per sq. dm. of anode surface. The solution should be agitated, and a D.C. current of 50 V. is required. Under these conditions, microscopic polishing of a surface previously prepared with 000 emery paper takes 4–5 min. It is stated that the attack of etching reagents is much more active on an electrolytically polished surface than on the same alloys polished mechanically, and a better contrast is obtained between the constituents.

Non-Destructive Testing. A. Salmony. (Automobile Engineer, 1939, vol. 29, July, pp. 249–252). The author explains the theory and principles of X-rays and gamma-rays and their application for examining ferrous and non-ferrous metals and other materials. He also presents illustrations of a variety of X-ray apparatus and of Siemens and Halske's electron microscope.

Atomic Pattern of Metals. W. L. Bragg. (Fourth Edward Williams Lecture : International Foundry Congress, London, June, 1939 : Foundry Trade Journal, 1939, vol. 60, June 15, pp. 506–508, 541). The author explains by means of simple analogies the theory of the X-ray diffraction method of determining the structure of metals and alloys.

The Radiographic Determination of the Notch Factor of Round, Notched Test-Pieces. H. Krächter. (Zeitschrift für Metallkunde, 1939, vol. 31, Apr., pp. 114–115). In the calculation of stresses at a change of section it is of great assistance to the designer to know the

notch coefficient of a material. This coefficient is the ratio of the maximum stress at the base of the notch to the known applied stress. In this paper the author describes a differential process using X-rays for determining the stress at the base of a notch in round specimens. He also shows that there is a critical point in the relation between the notch coefficient and the notch depth above which the notch coefficient decreases.

Some Things We Do Not Know about Steel. A. Sauveur. (Metal Progress, 1939, vol. 35, June, pp. 555–559). The author emphasises that there have been instances of theories of well-known scientists, although accorded general acceptance for many years, being eventually proved to be incorrect. He traces the changes in the theories concerning the allotropy of iron, the metastable micro-constituents of iron and steel, and the ageing of steel.

The Physics of Metals. III. and IV. P. Malaval and P. Bernard. (Mémorial de l'Artillerie Française, 1938, vol. 17, No. 68, pp. 685–730). In Part III. of this series (*see* Journ. I. and S.I., 1939, No. I., p. 370 A) the authors discuss the crystalline structure and the properties of metals with special reference to the Periodic Table of elements. In Part IV. they review the modern conceptions of alloy formation.

Effect of the Presence of Ferrite in Austenitic Chromium-Nickel Steels on the Decomposition of the Grains. R. Scherer, G. Riedrich and G. Hoch. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, July, pp. 53–57). The authors investigate the properties, structure and grain decomposition of austenitic chromium-nickel steels, and they find that when the steel contains 10–50% of ferrite the breakdown of the grains can be prevented by suitable heat treatment. These steels are prone to breakdown after heating for 1 hr. at 600° C., but heating for a long time, say 5 hr., prevents breakdown; this time can be reduced, however, if the temperature is increased to 900° C. Of the heat-treatable steels containing 10–50% of ferrite, only those containing 10–20% are of practical value, as a higher content than 20% causes loss of ductility. Austenitic chromium-nickel steels containing less than 10% of ferrite behave as pure austenitic steels, and those containing over 50% of ferrite do not break down after either short-time or long-time heating, but if they are heated to over 1000° C. they become prone to breakdown. The authors explain the recovery of chromium-nickel steels containing ferrite with suitable heat treatment by the theory that the chromium diffuses from the grain centres to the grain boundaries.

The Dendritic Structure of Some Alloy Steels. D. J. Martin and J. L. Martin. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1066: Metals Technology, 1939, vol. 6, June). The authors report on the examination of the influence of chromium, nickel, and molybdenum on the macro-structure of 4 × 4-in. ingots cast from a 60-lb. H.F. induction furnace and heat treated under closely controlled conditions. From

the results obtained they come to the following conclusions: (1) The effects of the above elements on the size and persistence of the dendritic segregation depend upon their effect upon the size and shape of the liquidus-solidus loop of the iron/iron-carbide diagram, and upon their effect on diffusion during and after solidification; (2) the typical colours imparted to the macrostructure by nickel, chromium and molybdenum are white, black and brown respectively; (3) the size of the dendrite increases rapidly with additions of nickel up to 3% and more slowly thereafter; and (4) chromium intensifies the effect of nickel.

Study of the Austenitic Grain of Steel and its Tendency to Grow. P. Bastien. (Revue de Métallurgie, Mémoires, 1939, vol. 36, Jan., pp. 1–10; Feb., pp. 53–63; Mar., pp. 101–111; Apr., pp. 194–200). The author presents in four parts a detailed study of austenite in steel. In the first he considers the solid solution of γ-iron or austenite which exists above the A_3 point, and explains the changes which take place in the crystalline structure as liquid steel solidifies. In the second he describes the processes by which the metallurgist studies the austenitic grain and some of the results obtained. In the third part he deals with the factors upon which the formation of austenite grains depends, and in conclusion he considers the properties of steel in relation to its grain size.

The Mechanical Effects of Intercrystalline Boundaries. B. Chambers. (Proceedings of the Physical Society, 1939, vol. 51, Part 5, No. 287). It is well known that the mechanical properties of a metal are greatly influenced by the size of the constituent crystals of the sample under test. Although the existence of this effect is well recognised, its explanation is by no means clear. In this paper the author discusses the available evidence by considering the results of experiments in which the number of grain boundaries is small, and by studying the way in which the presence of one or more boundaries causes the behaviour of the specimen to differ from that of a single crystal. He is of the opinion that crystal boundaries, when formed in a relatively pure metal, do not themselves modify the stress-strain characteristics of the crystals; but that the proximity of a second crystal raises the stress required to initiate slip to an extent which depends on the angle between the axes of the crystals, without altering the planes or directions that are effective. He does not apply this conclusion to the crystals of a polycrystalline aggregate.

Glide and Hardening in Metal Single Crystals. E. N. da C. Andrade. (Proceedings of the Physical Society, 1939, vol. 51, Part 5, No. 287). The author discusses a number of theories and the results of experiments relating to the plane and direction of glide in metal single crystals. He suggests the general conclusion that it is the glide direction which is fundamental, while the glide plane is determined by secondary considerations. Not only in the case of body-centred crystals, but also for the other crystals where tem-

perature has an influence on the glide plane, the glide direction is fixed, and is the most densely packed line. He deals also with the hardening produced in single crystals by strain which, at low temperatures, as measured by the resolved shear stress at different increasing strains, is particularly marked. In seeking an explanation of the fact that the hardening diminishes as the temperature rises, he observes that the glide packets (the comparatively undeformed slab of crystal between glide lamellæ) are thicker at high temperatures than at low. He finds, however, that the theory of hardening is not in a very satisfactory state, and suggests that among the experimental facts requiring further attention are the glide lamellæ and the crystalline rotations evidenced by the asterisms.

Lattice Distortion in Cold Worked Metals. G. W. Brindley. (Proceedings of the Physical Society, 1939, vol. 51, Part 5, No. 287). The purpose of this paper is to discuss the information obtainable from recent experiments on the intensities and widths of X-ray reflections from worked metals as to the nature of the distortion produced by cold working. The experiments have been carried out with microcrystalline metals, mainly in powder form with a crystal size sufficiently small (of the order of 10^{-4} cm. or less) to give continuous lines in the X-ray photographs. When measuring the intensities of reflections, it is desirable that the crystallites shall have a random orientation in the specimen, and this is most easily obtained with finely powdered metals.

Crystalline Structure and Deformation of Metals. W. A. Wood. (Proceedings of the Physical Society, 1939, vol. 51, Part 5, No. 287). A survey is made of changes in the crystalline structure of polycrystalline metals and large single crystals subjected to deformation by cold-work and by static and cyclic stressing, observations being made by a combination of mechanical, metallographic and X-ray tests. It is shown that the grains may be dispersed into crystallites characterised by a lower limiting size, depending on the metal, and that it is possible to observe internal lattice strains which it is considered are related to the process of strain hardening. It is also shown that the response of the crystalline structure depends on the manner, and particularly the speed, of application of stress, and that it is possible in this way to inhibit the dispersed crystallite formation and suppress the primitive yield point of a metal, thus varying the hardness independently of the external deformation.

The Structure of a Cold-Worked Metal. W. L. Bragg. (Proceedings of the Physical Society, 1939, vol. 51, Part 5, No. 287). In discussing the structure of a cold-worked metal the author considers an analogy between this structure and that of the nuclei of superlattice order in the alloy Cu_3Au. Picturing the formation of the nuclei, it is supposed that the different schemes start at random centres and grow; when they meet, they adjust their boundaries like the bubbles of a newly formed froth. He is of the opinion that a type *A* grows at the expense of a type *B*, or *vice versa*, over large

volumes in the crystal, and finds that this is borne out by measurements of electrical resistivity and energy content. These properties, when plotted against temperature, follow reversibly the same curves for all rates of heating and cooling.

Problems of Plastic Gliding. E. Orowan. (Proceedings of the Physical Society, 1939, vol. 51, Part 5, No. 287). The author points out that the crystallography of plastic gliding has in the past been considered from the so-called " static " concept, the essence of which was the assertion that no " true flow " exists. He describes an extensometer at the Physics Department of the University of Birmingham and discusses some experiments made with it with the object of studying the dynamic concept of plastic gliding. From some of the results obtained he deduces that the hardness of a crystal can increase by annealing, and that it can suddenly decrease by plastic deformation. Consequently the softness of real crystals is due to imperfections, and not to inherent structural characteristics of the lattice. In a mathematical discussion he develops a formula for calculating the rate of propagation of dislocations in crystals, and finds that this is a well-defined velocity less than the velocity of sound, even if the stress applied is higher than the critical stress necessary for moving dislocations without thermal help.

Internal Friction in Solids. C. Zener. (Proceedings of the Physical Society, 1939, vol. 51, Part 5, No. 287). By the term " internal friction " the author refers to the capacity of a solid to convert its mechanical energy of vibration into internal energy. It is the property which causes the gradual damping of the vibrations of a solid even when it is so supported as to transfer none of its energy to the surroundings. In this paper the author discusses thermo-electric currents and lattice dislocations as sources of internal friction in metals.

The Importance of Individual Crystallites of a Poly-crystalline Body in the Determination of Stresses Using X-rays. F. Bollenrath and E. Osswald. (Zeitschrift für Metallkunde, 1939, vol. 31, May, pp. 151–159). The influence is considered from the geometrical point of view, of stresses in the test-piece on the reflections of the crystallites composing it; and experimental results are given for a killed steel (0·11% of carbon) and for soft iron. These results indicate great differences between the interior stresses of the individual grains.

Transformation of Austenite on Cooling; Morphology and Genesis of the Aggregates Formed. H. Jolivet. (Iron and Steel Institute, 1939, this Journal, pp. 95P–114P). An attempt is made to draw up a classification of the structures which form in low-alloy steels during the isothermal decomposition of the austenite in the upper ranges (Ar′) and the intermediate ranges (Ar″). In addition to pearlite and troostite, the granular structures are described which have their origin in the lower portion of the upper range (Ar′), and for which there is no special designation. On the other hand, the author

adopts the term " bainite," which has already been suggested, to denominate the structures which appear in the Ar'' region, in preference to the terms acicular troostite, troosto-sorbite, troosto-martensite, &c. It is also shown that the structures observed are typical of their temperature of formation. They are governed by the relative extent of the growth of the elements formed and of the formation of new elements in relation to the fundamental quantities *Ng*, *Nc* (rate of nucleation and rate of crystallisation) connected with the crystallisation of the constituents. The analogies and specific characteristics of the structures in each of the regions are outlined, and an interpretation is given which suggests that the formation of the initial nuclei is due to two different constituents, *viz.*, cementite for Ar', and supersaturated ferrite for Ar''.

The Isothermal Transformation of Austenite during Cooling. A. Portevin and H. Jolivet. (Génie Civil, 1939, vol. 114, June 17, pp. 509–511). Two notes are reproduced which the authors have recently submitted to the Académie des Sciences. The first note deals with the formation of granular structures in the upper region of the transformation of steels. In the second note the specific types of structure which are formed by the partial decomposition of austenite during cooling are discussed, and their development is shown to depend on the temperature at which the steel has been held.

X-Ray Evidence of Intermediate Stages During Precipitation from Solid Solution. A. J. Bradley. (Proceedings of the Physical Society, 1939, vol. 51, Part 5, No. 287). Intermediate metastable structures resulting from the partial decomposition of solid solutions have been found in the copper-nickel-aluminium, iron-nickel-aluminium and iron-copper-nickel systems. In each case a single-phase structure, stable at high temperatures, breaks up into two phases on cooling. The first stage in the decomposition is the formation of islands, in which atoms are segregated prior to precipitation. The segregation takes place in the three systems as follows: (1) Islands of $CuNi_2Al$ segregate from a copper-rich solid solution; (2) islands of FeNiAl segregate from an iron-rich solid solution; these islands are recognised by the formation of the superlattices characteristic of the precipitating phases; and (3) during the decomposition of $FeCu_1Ni_3$ into two phases a laminated structure is produced, in which copper-rich laminæ alternate with laminæ rich in iron and nickel. Each has a tetragonal structure with the same a axes as in the former solid solution; in the copper-rich laminæ $c > a$; in the other laminæ $c < a$.

The Influence of Manganese on the Position of the Lines in Maurer's Diagram. L. S. Dlugach, V. Ya. Degtyareva and K. F. Starodubov. (Metallurg, 1938, No. 11, pp. 23–28). (In Russian). The effect of manganese (up to 2·9%) on Maurer's diagram (*see* Kruppsche Monatshefte, 1924, vol. 5, July, pp. 115–122) for the structure of cast iron was investigated using thirty-two different compositions with silicon from 0·61% to 3·22%, and carbon between

3·12% and 3·76%. The results were used to check the Maurer diagram for cast irons containing 1% of manganese and to construct a new diagram for cast irons with 2% of manganese. In the latter the dividing line between the pearlitic and ferrite-pearlite regions is shifted to the right and passes along the 2·75%-silicon ordinate. The boundary between the cementite-pearlite and pearlite regions is situated between the ordinates for silicon 1·2% and 1·5%. A space diagram of the Maurer type for cast irons containing between 1% and 2% of manganese is suggested. The authors also present some data regarding the effect of the cooling rate on the microstructure and hardness of cast irons with different manganese contents.

Niobium-Iron Alloys. R. Genders and R. Harrison. (Iron and Steel Institute, 1939, this Journal, pp. 29P–37P). The investigation comprises a study of the constitution of the niobium-iron system with particular reference to the phase changes occurring in the alloys of low niobium content. The phase diagram of the system is of the same type as that of tantalum-iron alloys. Up to 50% niobium the alloys may be considered as alloys of iron and a compound of composition approximating to Fe_3Nb_2. The solubility of this compound in α-iron is small at atmospheric temperatures but increases to 1·8% at the peritectoid temperature of 989° C.; its solubility in γ-iron increases with temperature from 1·0% at 989° C. to 2·0% at the eutectoid temperature of 1220° C. The data are complementary to the diagram of Eggers and Peter. Certain discrepancies are discussed. The addition of niobium to iron produces effects similar to those of tantalum, namely, a progressive increase in hardness with increase in niobium content and susceptibility to temper-hardening when water-quenched alloys of suitable composition are reheated. The properties of the niobium-iron alloys are of practical significance in connection with the industrial use of the metal as a constituent of weldable alloy steels and rapid-nitriding steels.

The Sigma Phase in Iron-Nickel-Chromium Alloys. (Metallurgist, 1939, vol. 12, June, pp. 37–39). An abridged English translation is presented of P. Schafmeister and R. Ergang's paper on the iron-nickel-chromium equilibrium diagram (*see* Journ. I. and S.I., 1939, No. I., p. 307 A), and the conclusions of these two authors are compared with those of other investigators, in particular Wever and Jellinghaus, and A. G. H. Anderson and E. R. Jette.

An X-Ray Investigation of the Iron-Rich Nickel-Iron Alloys. A. J. Bradley and H. J. Goldschmidt. (Iron and Steel Institute, 1939, this Journal, pp. 11P–27P). X-ray powder photographs of iron-nickel alloys have been taken after long times of heat treatment. They give unexpected results, which cannot be explained on the basis of current views. In spite of the fact that there are only two types of structure (body-centred cubic and face-centred cubic), the system is quite complicated. Reactions take place at two definite temperatures, 580° and 350° C. Below 580° C. there is a sudden

broadening of the two-phase gap, which is quite narrow above this temperature. From 580° down to 350° C. $\alpha + \gamma$ two-phase structures are formed at all compositions between about 6–8% nickel (α) and 23–26 atomic-% nickel (γ). At about 350° C. the α and γ phases react to form α_1 with the approximate composition Fe_3Ni, which is a low-temperature body-centred cubic phase. It is impossible to get direct evidence for the two-phase region $\alpha + \alpha_1$, because the lattice spacings are almost identical. The $\alpha_1 + \alpha$ region stretches from about 25 to 40 atomic-% nickel at 325° C. Invar, the composition of which places it in this region, must be regarded as a supersaturated γ solid solution which may under certain conditions of heat treatment precipitate Fe_3Ni.

The Iron-Zinc System I. H. Bablik, F. Götzl and F. Halla. (Zeitschrift für Metallkunde, 1938, vol. 30, Aug., pp. 249–252). The unit cell has been determined of the hexagonal crystals of the δ_1 phase of the iron-zinc system: $a = 12{\cdot}80 \pm 0{\cdot}01$ Å, $c = 57{\cdot}6$ Å, $c/a = 1{\cdot}130$ and $C_{6v}^4 = C6mc$ or $D_{6h}^4 = C6cmmc$. The unit cell consists of 550 ± 8 atoms and is thus the largest known for an intermetallic phase. There are no indications of a superlattice. For the investigation hard-zinc single crystals of about $\frac{1}{2}$ mm. length were used which had been found at the bottom of an industrial galvanising kettle.

The Iron-Zinc System II. F. Halla, R. Weil and F. Götzl. (Zeitschrift für Metallkunde, 1939, vol. 31, Apr., pp. 112–113). The monoclinic crystals of the ζ phase of the iron-zinc system were investigated by X-ray analysis and the following values were obtained: $a = 13{\cdot}65$ Å, $b = 7{\cdot}61$ Å, $c = 5{\cdot}06$ Å, $\beta = 128° 44'$; the space group is $C_{2h}^3 - C2/m$. The unit cell consists of two $FeZn_{13}$ molecules.

Dilatometric Investigation of the Iron-Nitrogen System. V. I. Prosvirin and G. I. Alekseeva. (Vestnik Metallopromyshlennosti, 1939, No. 1, pp. 72–77). (In Russian). Specimens containing 1%, 1·3% and 3·06% of nitrogen, respectively, were studied using the Chevenard type of dilatometer. The specimens were obtained by saturating the iron with nitrogen at 550° or 700° C., and quenched and unquenched specimens were used. The nature of the phase changes, the existence of which is indicated by the dilatometric curves, is discussed.

CORROSION OF IRON AND STEEL

(Continued from pp. 178 A–180 A)

Corrosion of Iron and Steel. (Metallurgist, 1939, vol. 12, June, pp. 33–34). Some criticisms are made of F. Eisenstecken's paper entitled " Present State of Our Knowledge on the Corrosion and Corrosion Protection of Iron and Steel " (*see* p. 178 A), and it is stated that this is a useful critical summary of directions in which progress in these fields has been made or is being attempted. A brief review of knowledge of the corrosion of iron and steel in a few general fields of service is then presented in three sections : (*a*) The atmospheric and (*b*) the marine corrosion of bare iron and steel, and (*c*) methods of application and functions of protective coatings of various kinds.

The *p*H, Dissolved Iron Concentration and Solid Product Resulting from the Reaction between Iron and Pure Water at Room Temperature. R. C. Cory and T. J. Finnegan. (American Society for Testing Materials, 1939, Preprint No. 101). A study was made of the reaction between iron and water at room temperature with special reference to the fundamental corrosion reaction. The work was conducted in iron vessels, and the water which was used was free from dissolved oxygen and carbon dioxide. This procedure eliminated these gases as factors and also insured the absence of impurities that might be introduced by contact with glass vessels. It was found that the solution reached a *p*H value of approximately 8·3 and contained about 0·2 parts per million of dissolved iron. The solid product of the reaction is predominantly ferric oxide. Previous investigators have reported *p*H values of the order of 9·0–9·6, but it is believed that the use of glass vessels was responsible for higher results than those reported here. Hypotheses of the fundamental corrosion reaction are discussed as well as the work of other investigators.

The Nature of Passivity in Stainless Steels and Other Alloys. I. and II. H. H. Uhlig and J. Wulff. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1050 : Metals Technology, 1939, vol. 6, June). In the first part of this paper the authors first of all review the literature on theories put forward to explain the resistance of stainless steels to corrosion. They discuss in particular the oxide-film and the hydrogen-solution theories of passivity, and describe an investigation of the surface and corrosion products of stainless steel by the electron diffraction method. The results of this investigation did not indicate the presence of an oxide film with a thickness of the order of 10 Å. or

greater, either crystalline or amorphous. The results did not, however, exclude the possibility of a film under certain conditions on the surface of stainless steel, but emphasised the necessity for investigating the properties of the surface metal atoms in order to account for all the phenomena observed. In the second part of the paper the authors outline and explain a new theory of passivity which is based on atomic energy and interaction without considering the more complex concepts of the metal lattice. They consider that the passivity of metals and alloys can be explained in terms of electron rearrangement within the metal and by the sharing of electrons between atoms. The sharing of electrons of iron by chromium atoms the authors denote as the mechanism whereby iron is made passive when alloyed with chromium. When one electron of an iron atom is so shared, it is considered to be in the passive state; when this sharing does not take place, it is in the active state. The authors conclude by pointing out that their theory has a large sphere of application, that it agrees with the known compositions of passive iron-chromium, iron-molybdenum, iron-nickel and iron-nickel-molybdenum alloys, and that it accounts for certain potential measurements in halide solutions which are difficult to reconcile with the oxide-film theory.

The Anodic Solution of Alloys. F. R. Morral and J. L. Bray. (Electrochemical Society, Sept., 1939, Preprint No. 6). In this study of the corrosion of metallic shafts and supports which are immersed in the electrolyte in continuous electro-cleaning units, the authors report on the causes and the rates of solution of 12 metals and 56 alloys. The electrolyte used was a solution containing 15–20% by weight of sulphuric acid. The authors found that the corrosion could be due to chemical solution, to local galvanic-couple action, or to stray currents when the metal shaft was the anode. They found that iron alloys containing 14% of silicon and those containing 25% of titanium corrode at one-twentieth and one-tenth respectively of the rate of corrosion of iron.

Relations between Crystal Structure and Corrosion. G. Derge. (Electrochemical Society, Sept., 1939, Preprint No. 23). The author shows that when a metal is applied to steel as a protective coating by electrolysis or any other method, the crystals of the protecting metal lie in some system of preferred orientation. He reviews the literature on this subject with particular reference to the relation between the preferred orientation and the corrosion-resisting properties of the coating.

A Classification of the Factors Causing Intergranular Corrosion. G. Chaudron. (Métaux et Corrosion, 1939, vol. 14, May, pp. 71–74). In this review of the causes and methods of preventing the intergranular corrosion of steel, the author considers the subject in three sections, *viz.*, the corrosion arising from the particular properties of the metal, that due to the manufacturing processes and that due to chemical attack.

Corrosion-Resisting Steels for Chemical Plant. J. H. G. Monypenny. (Proceedings of the Chemical Engineering Group of the Society of Chemical Industry, 1938, vol. 20, pp. 40–50). The author confines his discussion of corrosion-resisting steels to those which depend primarily for their corrosion resistance on an addition of chromium; these may contain notable amounts of other metals, particularly nickel. He considers the principal types of these steels which appear to be specially suitable for chemical plant, their main characteristics and the way they respond to manipulative processes.

Pitting Corrosion of Cast-Iron and Steel Pipes. L. Olsansky. (Institute of British Foundrymen (International Foundry Congress), June, 1939, Preprint No. 685). The author investigated the influence of the cast skin in the case of cast-iron pipes, and that of mill scale in the case of rolled steel tubes, on the resistance to corrosion by testing sections of these materials in a 5% solution of nitric acid. These tests showed that the presence of the cast skin or mill scale had a beneficial effect on the resistance to corrosion. (*See* next abstract).

Pitting Corrosion of Pipes. U. R. Evans. (Engineering, 1939, vol. 148, Aug. 4, pp. 145–146). The author refers to Olsansky's paper (*see* preceding abstract) and points out that although mill scale offers resistance to attack by nitric acid, it must not be assumed that its presence will retard corrosion by natural waters or soils, because the effect of contact elements on corrosion by nitric acid has long been known to be the reverse of their effect on corrosion by non-oxidising acids or waters.

New Methods of Protecting Buried Gas Pipes from Corrosion. G. Goos. (Gas- und Wasserfach, 1939, vol. 82, July 8, pp. 493–498). The author reviews progress made in methods of protecting the inner and outer surfaces of buried gas pipes from corrosion, and describes the results of tests on specimens of pipe which have been in use for a long time. He points out the importance of using a protective medium designed to combat the particular nature of the soil in which a pipe is to be buried. He deals also with corrosion caused by electric currents, with the use of bitumen and with tests on several kinds of paints used on the inner surface of pipes.

Recent Developments Relating to Soil Corrosion and Pipe Coatings. S. Ewing. (Proceedings of the American Gas Association, Twentieth Annual Convention, 1938, pp. 795–800). The author describes the progress that has been made within the last few years in determining the causes of soil corrosion and in improving the methods that are used to prevent it. Most of the information has been obtained from reports presented at the Bureau of Standards Soil Corrosion Conference, and the subjects dealt with include tests on pipes of copper joined to steel, methods of estimating the corrosive action of different soils, the work of the Dutch Corrosion Committee on the influences of bacteria on corrosion, and coating practice in different countries.

ANALYSIS

(Continued from pp. 113 A–118 A)

The Absolute Colorimetric Analysis of Metals. H. Pinsl. (Metallwirtschaft, 1939, vol. 18, May 19, pp. 417–419; May 26, pp. 437–441). The author reviews the papers and subsequent discussions on a photometric method of analysis which were read at the Zeiss Conference at Jena in September 1938. In this process the intensity of the light which passes through the reaction solution, or, in other words, the absolute amount of light absorbed by the solution within a narrow range of the spectrum, is determined with a high degree of accuracy.

The Use of Perchloric Acid in the Analysis of Ferrous Metals. Z. S. Mukhina. (Zavodskaya Laboratoriya, 1938, No. 2, pp. 162–164). (In Russian). In the analysis of high-alloy chromium-bearing steels, the previously suggested method of dissolving in a perchloric-hydrochloric acid mixture, followed by removal of the chromium as chromyl chloride was found to be ineffective, in that it did not give complete removal of the chromium. For complete separation, the treatment had to be repeated once or twice, depending on the composition of the steel. Several examples given show how this method of removing the chromium simplifies the subsequent determination of other alloying elements such as titanium, vanadium, and cobalt.

Perchloric Acid. Part IV. C. M. Johnson. (Iron Age, 1939, vol. 143, June, pp. 32–35, 68). Continuation of a series of articles (*see* p. 113 A). In the fourth part of this series the author outlines the procedure for the determination of nitrogen in chromium, chromium-nickel-molybdenum steel, and in coal and coke by solution in hydrochloric and perchloric acids.

A Rapid Method for Determining Carbon in Plain Carbon Steels, for Control Purposes. H. H. Blosjo. (American Foundrymen's Association, May, 1939, Preprint No. 9). The author describes a rapid method of determining the carbon in plain carbon steels. With this method the instrument can be placed near the furnace and the melter can make his own determinations. The method consists of comparing the magnetic permeability of a bar of the steel of unknown carbon content with that of a bar of known carbon content. The essential feature of the instrument is a ballistic galvanometer which responds to the difference in potential between two coils the cores of which consist of the specimens being compared. The time required from pouring the test sample to completing the determination is about 2½ min.

The Quantitative Polarographic Determination of Alloy Additions in Special Steels. M. v. Stackelberg, P. Klinger, W. Koch and E. Krath. (Technische Mitteilungen Krupp, Forschungsberichte, 1939, vol. 2, June, No. 6, pp. 59–85). After a lengthy introduction on the principles of the polarographic method the authors describe a new form of the dropping cathode which allows the production of absolutely reliable standard curves. Thus no standard solutions are required for subsequent analyses. Methods have been developed for the polarographic determination in steel of manganese, nickel, cobalt, molybdenum, tungsten and vanadium. The polarographic method, in its present state, is said to be not yet suitable for routine analyses of steel as the chemical preparation of the samples to be analysed is too elaborate. The method might prove very suitable, however, for micro-determinations of alloy additions to steel.

The Determination of Aluminium in Steel. Part II.—The Determination as Oxide and Hydroxyquinolate. P. Klinger. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, July, pp. 21–36). After a critical survey of the literature on the reagents used for the determination of aluminium precipitated as aluminium hydroxide, the author discusses in detail other methods of determining this metal by precipitation with (*a*) ammonia; (*b*) potassium iodide-potassium iodate; (*c*) ammonium-, sodium- or potassium-nitrite; and (*d*) hydroxyquinoline. He also examines the effects of alloying elements such as copper, manganese, nickel, chromium, titanium, vanadium, molybdenum and tungsten, upon the accuracy of the results obtained. The author has previously discussed the determination of aluminium as phosphate (*see* Journ. I. and S.I., 1935, No. I., p. 528 A).

The Determination of Cobalt in Steels and Alloys. G. J. Steele and J. J. Phelan. (General Electric Review, 1939, vol. 42, May, pp. 218–220). Some minor modifications are suggested in connection with Dickens and Maassen's electrometric determination of cobalt (*see* Journ. I. and S.I., 1936, No. I., p. 151 A).

Hydrogen in Solid White Cast Iron. H. A. Schwartz and G. M. Guiler. (American Foundrymen's Association, May, 1939, Preprint No. 4). The authors describe a direct-combustion method of determining the hydrogen in solid white cast iron. Using this method they find that white iron may contain 0·0002–0·0015% of hydrogen, and further investigations showed that most of the hydrogen is driven off on heating when the temperature reaches 800° C.

Analysis of Lead in Carbon Steel. A. E. Pavlish, J. D. Sullivan and J. Shea. (Metals and Alloys, 1939, vol. 10, May, pp. 150–151). The authors describe a gravimetric method of determining lead in carbon steel. This method was developed at the laboratories of the Battelle Memorial Institute. The process consists of dissolving the sample in hydrochloric acid and passing sulphuretted hydrogen through the solution which is then filtered. The precipitated sulphides

are then dissolved in nitric acid, to which a little sulphuric acid is subsequently added and the solution is evaporated. A filtrate of lead sulphate is obtained at the completion of the process from the weight of which the amount of lead is determined. The accuracy of the results obtained is very good.

Photo-electric Method of Determining Phosphorus in Plain Carbon Steels. A. Ya. Bursuk. (Zavodskaya Laboratoriya, 1939, No. 1, pp. 12–16). (In Russian). Preliminary experiments for the determination of phosphorus in steel showed that in acid solutions sodium sulphite has a selective reducing action on the phosphomolybdate compound, the intensity of the blue colour obtained being proportional to the amount of the compound present. In the method described by the author, the sample is dissolved in nitric acid, the phosphorus is oxidised with permanganate and the iron oxide reduced with sodium sulphite, while the actual determination is carried out in a portion of the solution acidified to 0·5*N* with hydrochloric acid. Under these conditions the presence in solution of up to 0·5% of silicon, up to 0·03% of arsenic and of nitrates does not interfere. Using a photo-electric colorimeter incorporating a selenium cell, the phosphorus can be determined in 17–20 min. within 0·001–0·002%.

A Rapid Method of Determining Silicon and Phosphorus in Cast Iron. S. N. Shkotova. (Zavodskaya Laboratoriya, 1939, No. 2, pp. 213–214). (In Russian). The silicon in 1–2 g. of grey cast iron dissolved in *aqua regia* is determined after twice evaporating the solution, by precipitating from boiling nitric acid solution in the presence of gelatine. The precipitate is ignited and weighed. The filtrate is treated by boiling with permanganate, the excess of which, and the precipitated manganous oxide, are decomposed by sodium nitrite, after which the phosphate is precipitated with molybdate. An analogous method is described for white cast iron.

Processes for the Photometric Determination of Vanadium in Tool and High-Speed Steels. G. Bogatzki. (Archiv für das Eisenhüttenwesen, 1939, vol. 12, May, pp. 539–542). The author describes a rapid and reliable photometric method of determining the vanadium present in alloy steels. The method is based upon the fact that phosphoric acid and ammonium molybdate will react with a solution containing vanadic acid turning it yellow. He explains how to convert the vanadium to vanadic acid without converting any chromium which may be present to chromic acid.

New Method of Determining Iron with Potassium Ferrocyanide. M. A. Bodin. (Zavodskaya Laboratoriya, 1939, No. 1, pp. 32–33). (In Russian). The method for the determination of iron described by the author is as follows : To 100 c.c. of the test solution containing not less than 3 mg. of ferric iron, 5 c.c. of a 10% solution of ammonium thiocyanate and 10 c.c. of *iso*amyl alcohol are added. The ferric thiocyanate is extracted into the layer of *iso*amyl alcohol by shaking and the solution is then titrated (with frequent shaking)

with a solution of potassium ferrocyanide. The end point is indicated by the fading of the *iso*amyl alcohol layer, which functions as an indicator.

Copper Sulphide in Steel. A. Skapski, A. Kotlinski and W. Goslawski. (Annales de l'Académie des Sciences Techniques à Varsovie, 1939, vol. 6, pp. 23–33). The authors refer to their previous work on electrolytic methods of separating and determining non-metallic inclusions in steel (*see* Journ. I. and S.I., 1937, No. II., p. 295 A), and now describe in detail the analytical procedure that they have developed for the separate determination of the sulphides of copper, manganese and iron present in the residues obtained by electrolysis. In this electrolysis the specimen forms the anode, and it is suspended in a solution of 8% sodium citrate and 1% potassium bromide; this solution lies upon a quantity of glycerine contained in the same vessel. The residue from the electrolytic action is periodically shaken down by means of a magnet and falls into the glycerine, which protects it from the possibility of attack by the electrolyte. The cathode is a copper sheet immersed in a saturated solution of copper sulphate, which is kept up to strength by having suspended in it a filter paper containing powdered copper sulphate. The residue is recovered from the glycerine and is washed, ground, washed again, and is then ready for analysis. Extraction of the residue with cyanide in caustic soda solution with nitrogen bubbled through it removes metallic copper and copper sulphide; no hydrogen sulphide should be evolved, as shown by passing the nitrogen through cadmium acetate. The filtered solution is treated with bromine to convert the sulphide to sulphate, and the latter is precipitated with barium; from the weight of barium sulphate the copper sulphide in the residue is calculated. The residue is next treated in sodium acetate solution under nitrogen; all the manganous oxide is extracted and estimated, but some manganese sulphide is attacked; the hydrogen sulphide evolved from the latter is carried over by the nitrogen into a cadmium acetate solution, and is there estimated. The residue is next stirred vigorously with copper ammonium chloride to decompose carbides, and, after filtering, is treated with cyanide solution under nitrogen; the solution is analysed for sulphate, which is calculated to manganese sulphide. The residue is next extracted overnight with dilute sulphuric acid, nitrogen being bubbled through it energetically; this decomposes manganese sulphide, but not ferrous sulphide. The acid solution is analysed for manganese, the sulphur carried over in the nitrogen is estimated, and both figures are calculated to manganese sulphide. The residue is now digested on the water-bath with a solution of citric acid and sodium citrate under nitrogen; the iron in the liquid is calculated to ferrous oxide, and any sulphur in the nitrogen is calculated to ferrous sulphide. The remaining residue is boiled with hydrochloric acid, nitrogen being passed; the iron sulphide is decomposed and the hydrogen sulphide generated is carried over by the nitrogen

and estimated by absorption in cadmium acetate, and from this the iron sulphide is calculated.

Having described these procedures, the authors discuss certain check tests, the results obtained and the reasons for the sequence of the determinations described above. Their determinations all lead to the conclusion that the amount of ferrous sulphide present in copper-bearing steels is almost negligible and that the sulphur in these steels is fixed by the manganese and the copper and not by the iron. The authors also show that this theory is in agreement with the thermodynamic conditions of the sulphur equilibrium in molten steel. In their concluding general remarks they point out that as the proportion of copper sulphide to the other sulphides present in steel increases, the melting point of the sulphide inclusions will be lowered. The mechanism of the transition from cuprous sulphide, which exists at the temperature of molten steel, requires further investigation; in this respect the rate of cooling of the ingot appears to be of greater significance than the subsequent heat treatment of the steel.

Recent Developments of Spectrographic Analysis. II. E. van Someren. (Metallurgist, 1939, vol. 12, June, pp. 44–46). Continuation of a series of articles (*see* p. 117 A). The author reviews a number of recent contributions to the literature on spectrographic analysis applied to metallurgy. A bibliography with eighteen references is appended.

The Fundamental Principles and Value of Fuel Testing. A. S. Bean and J. Brown. (Institute of Fuel, Apr., 1939: Engineering, 1939, vol. 147, June 2, pp. 662–663). As it is generally acknowledged that solid fuels present difficulties in sampling and that the greatest difficulties are encountered in coal, the authors restrict their remarks to coal, pointing out however that their views on coal apply to all solid fuels but with varying force. They present a diagram showing the flow of coal from the seam to the various forms in which it is marketed and explain the selection of points at which samples should be taken with particular reference to the work of Grumell and Dunningham and the procedure laid down in British Standard Specification No. 502, 1933.

BOOK NOTICES

(Continued from pp. 181 A–182 A)

HILTON, B.R. "*Engineering Machine Shop Practice.*" 8vo, pp. x + 183. Illustrated. London, 1939 : Sir Isaac Pitman & Sons, Ltd. (Price 6*s*.).

In this small book, intended for engineering students and apprentices, an attempt has been made to cover the fundamental principles of machine-shop practice, the object being two-fold. In the first place, it has been written as an aid to practical work, and its second purpose is that it shall serve as a guide to the technology of this subject. Thus, it covers both tool-room practice and production work, more particularly small-scale production work, and relates more specifically to the operations, tools and machines used. Large-scale production and the underlying principles are not included, nor could such a treatment be covered within the compass of less than two hundred pages. The text must therefore be read as applying more especially to tool-rooms and small machine-shops than to quantity production. The subjects treated are measuring instruments and marking-out preparatory to machining; sawing, hacksaws, and blades; the use of the cold chisel; files; machining operations, such as lathework, shaping, milling, drilling; hand operations, such as filing, scraping and polishing, tapping and screwing. Each section is treated first by describing the various types of tools available and the specific applications of each, and then by giving fairly detailed and useful tips as to correct use. As this knowledge is likely to prove of considerable help to engineering students and apprentices, it is hoped that the author can be persuaded to extend the range covered in any later edition published. For instance, the section devoted to measuring instruments might well be expanded to include the optical equipments now in common use both in the tool-room and the machine-shop, such as thread gauges and contour projectors. Also, despite the fact that many of the machines described are of interest to the beginner as well as to more advanced users, they require often very considerable modification to render them suitable for the production of components in even moderate quantities. For these reasons, it is suggested that an extension of the work on the lines indicated would add very considerably to the value of the book.

WILLIAM F. CHUBB.

INTERNATIONALE SCHIENENTAGUNG. "*Bericht über die IV. Internationale Schienentagung veranstaltet durch Deutsche Reichsbahn und Verein Deutscher Eisenhüttenleute in Düsseldorf*, 19. *bis* 22. *September* 1938." pp. viii + 255. Illustrated. Düsseldorf, 1939 : Verlag Stahleisen m.b.H. (Price 15 RM.).

This publication contains a full report of the proceedings at the Fourth International Rail Congress held at Düsseldorf from the 19th to the 22nd September, 1938. The origin of these congresses was referred to in the opening speech of the president, Professor Dr.-Ing P. Goerens,

when he welcomed Professor Roš, saying that it was he who suggested, at the International Congress on Material Testing in 1927, that it would be a good thing for rail producers and rail users to get together and pool their experience. The first and second congresses were held at Zürich and the third at Budapest in 1935. The publication is in two parts, the first consisting of the papers read at the opening and six subsequent meetings, whilst the second commences with the addresses of welcome and closing speeches, which are followed by the discussions of the papers in chronological order. The present volume contains the following thirty-three papers: The Importance of Railways to Traffic, by K. Remy; The Rail—A Metallurgical Service and a Metallurgical Problem, by E. H. Schulz; Amount of Internal Stresses in Rails Treated in Various Manners, by K. Schönrock; The Tendency of a Straight Jointless Track to Warp Due to Thermal Stresses, by M. T. Huber; The Railway Track from the Point of View of the Protection of Warping, by T. Raab; The Effect on the Permanent Way of Stresses in Long Lengths of Flat-Bottomed Rail Track, by W. Hüttner. The Theory of Mechanical Wear, by C. Zocchi; The Influence of Test Conditions when Testing Wear Resistance, by E. Siebel; Wear-Resistance Tests of Steels for Rails and Tyres, by A. Eichinger; X-Ray Examination of Wear Surfaces on Rail Steels, by E. Brandenberger; The Wear of the Running Surface of Tram Rails, by H. O. Lange; Examination of Corrugated Rails, by R. Kühnel; Statistics of Broken Rails of the Deutsche Reichsbahn, by V. Hervig; Notched-Bar-Impact Strength of Railway Rails Broken in Service, by J. Bartel; What Do 25-Years' Statistics on the Life of Rails in the Track Teach Us? by G. Mandel; Experience with Grooved Rails in Tramway Service, by G. Kühn; Laboratory Tests and Experiences with Ordinary, Compound and Heat-Treated Steel Rails, by M. Roš and A. Bianchi; The Examination of Rail Steels by X-Rays, by E. Brandenberger; Suitable Acceptance Tests for Rails, by R. Kühnel; A Numerical Comparison of the Segregation in Rolled Steel Sections, by C. C. Teodorescu and St. Nadaşan; The Effect of Shape and Quality of Material on the Life of Railway Material, by P. Forcella; Improvement of the Base of Rails by a Special Rolling Process, by F. Daussy; The Exceptional Wearing Properties of Early Steel Rails and their Reproduction in Modern Rail Manufacturing Conditions, by C. J. Allen; Advancement in the Metallurgy of Steel for Permanent Way Material in Austria, by R. Walzel; A Comparison of Corrosion Tests on Rail Steels, by J. Friedli; The Determination of the Best Profile for a Rail Web, by R. V. Baud; Thermit Welding for Making Long Rails and Jointless Track, by J. Wattmann; Experiments on the Resistance-Welding of Rails, by J. E. Languepin; Comparative Investigation of Hard Rail Steel Electrically Welded Manually and Automatically, by D. v. Csilléry and L. Péter; The Development of the Oxy-Acetylene Welding of Rail-Joints, by R. Dümpelmann; Non-Uniformity in the Welding of Rails, by F. Benesch; Uniform Conditions for the Testing and Acceptance of Welded Rail-Joints, by J. Nemesdy-Nemcsek; and The Most Important Aspects of the Technical and Economic Valuation of Rail-Joint Welding, by P. Tulacz. Great care has been taken in the compilation of this volume to make it a useful and international work of reference to metallurgists, testers, welders, producers and users of rails, for in addition to the index in four languages (German, Italian, English and French) there are also summaries of all the papers and discussions in these languages. The quality of all the illustrations and diagrams is perhaps even better than the usual high standard of reproductions in the German technical literature. Abstracts of the papers read at this Congress will be found in Section II. of the Journal of the Iron and Steel Institute, 1938, No. II.

TONGUE, H. "*A Practical Manual of Chemical Engineering.*" With a Foreword by Sir Gilbert Morgan. 8vo, pp. xv + 560. Illustrated. London, 1939: Chapman and Hall, Ltd. (Price 36*s.*).

The author of this highly informative book on the practical aspects of chemical engineering has been systematically collecting and testing practical data relating to the design and construction of chemical plant over a period of twenty years, and, in response to suggestions made from time to time by friends and colleagues, he has undertaken the task of arranging and amplifying his notes to form this volume. Realising that it would be impossible to deal in one book with the whole field of chemical engineering, he has endeavoured to select what are generally regarded as the most important aspects of the subject, and has confined attention to these. The result is a work that fills a definite gap in technical literature, and should prove of great value to those engaged in the day-by-day problems of chemical plant design and operation, as well as to those taking courses of instruction with a view to entering the manufacturing side of chemical industry. It should also be of interest to many metallurgists, for although no attempt is made to deal with metallurgical engineering as a branch of chemical engineering, a considerable amount of attention is given to metals as the most important materials used in the construction of plant, and as the chemical industry uses large amounts of metals under conditions which differ from those prevailing in other industries, the views of a chemical engineer on metals are worthy of attention. Actually the first four chapters are devoted specifically to metals, the first three dealing with non-ferrous metals, cast irons and steels respectively, and the fourth with the properties of metals at high and low temperatures. The metals considered are those of most importance to the chemical engineer, and particular attention is given to corrosion resistance, welding, and the applications of specific metals in specific processes. The chapter on the properties of metals at high and low temperatures is, of course, concerned more with high than low temperatures, and contains a discussion of creep, the use of creep data in design, and the properties and treatment of heat-resisting steels. In these four chapters there is much to interest metallurgists who are concerned with the applications of metals. The fifth chapter deals with non-metallic materials of construction, and the remainder of the book is devoted to the engineering aspects of the design and construction of pressure vessels, pipes and pipe-work, steam plant, evaporators, filters &c., and to the phenomena associated with drying, adsorption, distillation, crushing, grinding &c. The design and operation of chemical plant from the safety aspect are considered in an appendix.

J. M. ROBERTSON.

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REFRACTORY MATERIALS

(Continued from pp. 128 A–130 A)

Evaluation of the Squatting Temperatures of Cones Used for the Determination of Refractoriness. V. H. Stott. (Transactions of the British Ceramic Society, 1939, vol. 38, June, pp. 341–354). The author describes the apparatus and procedure employed during an investigation at the National Physical Laboratory with the object of testing the squatting temperatures of English Seger cones 26 to 35.

Refractory Material for the Iron Industry. I. Sjöström. (Jernkontorets Annaler, 1939, vol. 123, No. 4, pp. 165–190). (In Swedish). In this comprehensive review of the properties and applications of modern refractory materials used in the iron and steel industry, with particular reference to those used in Sweden, the author deals with the subject under the six headings: fireclay bricks, silica bricks, basic bricks, plastic lining materials, stoppers and nozzles. His information is based largely on the results of laboratory- and full-scale work at the Höganäs steelworks. He refers to the improvements which have resulted from burning firebricks in tunnel furnaces, which has improved the uniformity of the quality, and to the dry-pressing process, which reduces the porosity. He states that during the last few years a silica brick has been manufactured in Sweden from Swedish raw materials and this is now taking the place of German and British silica bricks in Scandinavia. Its analysis is: silica 96·4%, alumina 0·8%, ferric oxide 0·7%, lime 2·0% and magnesium oxide 0·1%; the softening point is about 1680° C. With regard to basic bricks, Sweden imports the whole of her requirements; magnesite of suitable quality does occur in Lappland, but there are no transport facilities to bring it to the industrial districts. A new method of making both magnesite and chrome-magnesite bricks without burning, but using a chemical binder, has been developed. In this method the bricks are pressed under extremely high pressure (up to 1000 atm.), with the result that the dimensions of the finished brick are more accurate than those of burned bricks. When these bricks are first brought up to temperature the chemical binders become weaker between 900° and 1000° C., at a slightly higher temperature the components of the brick sinter, and, when a temperature of 1300° C. is reached, the brick regains its original strength. At steel-making temperatures, therefore, these bricks behave just as well as bricks burned in the manufacturing process, and experience has shown they can be used in walls of open-hearth furnaces. It has been found, however, that these bricks cannot always be re-used after repairing a furnace.

Selection and Testing of Cupola Refractories. W. J. Rees. (International Foundry Congress, June, 1939 : Foundry Trade Journal, 1939, vol. 61, July 27, pp. 63–65). The author describes three ways of lining cupolas. (1) Using firebricks; (2) with bricks or blocks cut to shape from a natural siliceous rock or " firestone "; and (3) with a plastic or semi-plastic material having either a silica or burned-fireclay base, rammed round a former. He also compares the properties of these materials with special reference to their resistance to slag.

The Impact Strength of Refractory and Ceramic Materials and its Determination. B. Ya. Pines and I. L. Rotenberg. (Zavodskaya Laboratoriya, 1939, No. 3, pp. 308–315). (In Russian). Results of impact tests on a Charpy pendulum machine lead to the conclusion that a straight-line relationship exists between the impact strength of several refractories and the square of the velocity of impact. It is therefore concluded that the values obtained in no way correspond to the impact-strength characteristics of the materials tested, the greater part of the impact energy being used up in supplying kinetic energy to the fragments of the test-piece and in setting up vibration in the base of the instrument. Much more reliable figures for the work required to fracture the test-piece can be obtained from static bend tests, in which the deflection is measured by an optical method. This is true even in the case of magnesite, which undergoes a small amount of plastic deformation before fracturing.

The Application of Sillimanite as a Material for Constructing Arches for Electric Arc Furnaces. (Stahl und Eisen, 1939, vol. 59, June 15, p. 713). A brief account is given of the properties and advantages of using sillimanite bricks for the roofs of electric arc furnaces. It is stated that the best composition is : Silica 37–39%, alumina 55–60%, ferrous oxide about 1%, titanium oxide 1·5% and total alkalis about 1·0–1·1%. Such bricks have a very high resistance to thermal shock, for a good sillimanite brick can be quenched in water from 1000° C. more than sixty times without fracture.

The Behaviour of Powdered Magnesite under Conditions Prevailing in the Arc Steel Melting Furnace. V. M. Zamoruev. (Metallurg, 1939, No. 3, pp. 46–55). (In Russian). The conditions of service of the lining in arc furnaces are much more severe than in the open-hearth furnace. Cooling below 675° C. after tapping causes the transformation of the absorbed β-$2CaO.SiO_2$ slag to the α-form. As this change is accompanied by an increase in volume, it has a very destructive action on the lining. Unfavourable factors are also the much longer time during which the metal is in contact with the lining and the compositions of some of the slags used. Examination of a number of samples of magnesite led the author to the conclusion that the magnesite used should have a specific gravity of 3·50 and porosity 35–40% and there should be no pieces too large to pass

through a 15-mm. screen. The chemical composition should be magnesia 90–91%, lime 2·6%, silica 3·8%, alumina 1·0%, ferric oxide 2–3% and loss on ignition 0·60%. Examination of a sample from a good lining showed that it consisted mainly of a forsterite matrix and fine grains of periclase uniformly distributed among the comparatively large grains of forsterite. Small amounts of glass and melilite were also present.

A Satisfactory Refractory for the Bottoms of Ingot Heating Furnaces. A. Kramarenko and L. Tseytlin. (Stal, 1938, No. 11, pp. 27–35). (In Russian). By way of introduction, practice relating to the choice of refractories for furnace bottoms and the properties of these refractories are surveyed. Some preliminary laboratory experiments were carried out by heating different refractories in an electric furnace in contact with low-carbon steel in order to study the effect on the refractories of the scale formed on the steel and also the effect of the refractories on scaling. Particularly good behaviour was observed in the case of chrome bricks (using a forsterite bond) and chrome-base concrete. The subsequent laboratory and large-scale experiments on furnace bottoms were therefore conducted on chromium-bearing concretes bonded with aluminous cement with and without the addition of magnesite. The refractoriness-under-load of chrome concrete rose on increasing the aluminous-cement content up to 20%. In the case of the chrome-magnesite concretes (25% magnesite) the cement content should be about 15%. The refractoriness of both concretes is above 1750° C. It was found that furnace bottoms made of this chrome-magnesite concrete tended to reduce scaling of the ingots. Any scale formed did not penetrate deeply into the refractory, and scale fused on to the surface could be easily chipped off.

FUEL

(Continued from pp. 185 A–187 A)

Analyses of Pennsylvania Bituminous Coals. (United States Bureau of Mines, 1939, Technical Paper 590). In this comprehensive survey of the coalfields of Pennsylvania very complete information is presented concerning the occurrence, reserves, quality, characteristics, production, uses and analyses of the bituminous coals of this State.

Classification Chart of Typical Coals of the United States. A. C. Fieldner, W. A. Selvig, and W. H. Frederic. (United States Bureau of Mines, 1939, June, Report of Investigations No. 3296R). The authors present tables and charts in which coals from 316 American mines are classified by rank. The tables also give information on their calorific value and their coking and weathering properties.

The Application of Electric Dedusting in the Coal Industry. R. Rapinat. (Revue de l'Industrie Minérale, Mémoires, 1939, No. 440, June 15, pp. 221–227). After briefly reviewing wet and dry processes of cleaning coal, the author gives some particulars of the capacity, current consumption and efficiency of electric dedusting equipment used in conjunction with driers for treating the wet sludge from coal-washing plants.

New Processes of Washing Coal in Suspensions of Dense Materials. H. Verdinne. (Annales des Mines de Belgique, 1939, vol. 40, No. 2, pp. 431–472). After discussing the general principles of the use of dense media for washing coal and the degree of efficiency which is obtainable by this process, the author describes a number of such systems, including the Chance, the Jan de Vooys, the Dutch State Mines and the Tromp processes.

Cleaning of Coal by Heavy Liquids, with Special Reference to the Staals-Mijnen-Loess Process. M. G. Driessen. (Journal of the Institute of Fuel, 1939, vol. 12, Aug., pp. 327–341). The author describes the process introduced by him for the cleaning of coals. (*See* Journ. I. and S.I., 1939, No. II., pp. 63 A and 131 A).

A Washability Study of the Black Creek Coal Bed at Yolande No. 6, Rockcastle, Ala. B. W. Gandrud, G. D. Coe and J. C. Mead. (United States Bureau of Mines, 1939, June, Report of Investigations No. 3450).

Selection of Coal for Pulverized Firing. B. E. Tate. (Transactions of the American Society of Mechanical Engineers, 1938, vol. 60, pp. 11–16). The author discusses the selection of suitable coal for use in pulverised-fuel fired boiler plants. He deals in particular with the following characteristics: (*a*) "Use value," *i.e.*, the value of the

coal in relation to all the other plant costs, not merely in relation to the amount of steam produced; (*b*) calorific value; (*c*) grindability; (*d*) content of volatile matter; (*e*) moisture content; (*f*) ash fusion temperature; (*g*) ash content; (*h*) size of particles; (*i*) foreign material; and (*j*) amount of ash passing to the flues.

Combustion of Pulverized Coal. H. Kreisinger. (Transactions of the American Society of Mechanical Engineers, 1938, vol. 60, pp. 289–296). The author considers the factors affecting the combustion of pulverised coal in furnaces with water-cooled steel walls. The factors considered are the control of the air supply, the size of the fuel particles, the percentages of moisture and volatile matter, the ash, the oxygen concentration and the furnace temperature.

The Distribution of Energy in the Pulverized-Coal Furnace. W. J. Wohlenberg and D. E. Wise. (Transactions of the American Society of Mechanical Engineers, 1938, vol. 60, pp. 531–547). In a mathematical discussion the authors develop formulæ for calculating the transfer and distribution of energy which takes place in a furnace fired with pulverised coal. They analyse the whole process of combustion and determine the relative importance of the heat transferred by radiation and conduction from the coal particles, the ash particles and from the gases.

Rehabilitation of a Battery of Vertical Flue Coke Ovens. E. R. Merrill. (Iron and Steel Engineer, 1939, vol. 16, July, pp. 27–33). The author describes the extensive repairs and alterations carried out in 1937 on forty of a battery of eighty coke-ovens of the Woodward Iron Co., Woodward, Alabama.

Coke-Oven Reconstruction and Gas-Purification Plant. (Coke and Smokeless-Fuel Age, 1939, vol. 1, July, pp. 49–51). A brief illustrated description is given of the new coke-oven and by-product plant at the Kidsgrove collieries of the Birchenwood Coal and Coke Co., Ltd. The new battery comprises 17 Simon-Carves Otto compound underjet ovens with a total capacity of 400 tons of wet coal per day; the carbonising time is 18 hr.

Expansion of Coal during Coking. H. S. Auvil, J. D. Davis and J. T. McCartney. (United States Bureau of Mines, 1939, May, Report of Investigations No. 3451). The authors describe two experimental coke-ovens, one heated in one side-wall and the other heated through the bottom, and describes their use in determining the swelling properties of a number of American gas and coking coals. These tests are a continuation of those described in Report of Investigations No. 3403. (*See* Journ. I. and S.I., 1938, No. II., p. 266 A).

The Mechanism of Coking Bituminous Coals and Their Mixtures. L. M. Sapozhnikov. (Coke and Smokeless-Fuel Age, 1939, vol. 1, June, pp. 27–29; July, pp. 58–60). The author describes the apparatus used, the experimental technique and the results obtained in his investigation of the plastic properties of some Russian coking coals.

Recovery of Sulphur from Fuel Gases. A. R. Powell. (Industrial and Engineering Chemistry, Industrial Edition, 1939, vol. 31, July, pp. 789–796). The author reviews the more recent methods developed in the United States and in Europe for the recovery of sulphur from fuel gases of all kinds.

A Comparison of Charcoal Carbonised in Heaps With and Without Chimneys. H. Bergström. (Jernkontorets Annaler, 1939, vol. 123, No. 3, pp. 155–162). (In Swedish). The author reports on an investigation of five different kinds of Swedish charcoal which had the object of determining the different effects of carbonising in heaps with and without a chimney upon the following properties: (*a*) The dry weight; (*b*) the moisture content; (*c*) loss on ignition; (*d*) phosphorus content; and (*e*) reduction in volume while being transported in a railway truck. The results showed that the charcoal carbonised in heaps with a chimney was in all respects better than that carbonised in heaps without a chimney.

The Supply of Wood for Charcoal and Charcoal Production. H. Bergström, D. Höglund and M. Nordquist. (Jernkontorets Annaler, 1939, vol. 123, No. 1, pp. 1–38). (In Swedish). The authors present a comprehensive account of the available source of wood in Sweden for the production of charcoal, and include a number of tables showing the quantities and values of the charcoal produced and consumed in the different provinces during the last few years.

PRODUCTION OF IRON

(Continued from pp. 188 A–191 A)

No. 1 Blast-Furnace at the A.I. & S. Ltd. Kembla Works. J. W. Thompson. (Broken Hill Proprietary Review, 1939, vol. 16, June, pp. 14–15). A brief description with five illustrations is given of the No. 1 blast-furnace of Australian Iron and Steel, Ltd., Kembla Works. This furnace and some of the equipment were recently reconditioned and a short account of this work is included.

Blast-Furnace Skip and Top Direct Current Control. H. L. Wilcox. (Iron and Steel Engineer, 1939, vol. 16, July, pp. 9–18). After describing the sequence of operations necessary for the charging of a modern blast-furnace producing about 1000 tons of pig iron per day, the author describes in detail the electrical circuits and switches which provide a flexible method of controlling the skip-hoist and bell mechanism at one of the blast-furnaces of the Republic Steel Corporation at Youngstown, Ohio.

" Air Conditioning " of Woodward Pig Iron. (Iron Age, 1939, vol. 144, July 20, pp. 38–39). A brief account is given of a dehumidifying unit installed at the blast-furnaces of the Woodward Iron Co., Birmingham, U.S.A., which removes the moisture from the blast before it passes to the stoves. The moisture is removed by passing the air through sprays of cooled water, which brings its temperature down to 40° F. It is expected that the quality of the iron produced will be more uniform and that the coke consumption will be reduced by the use of this auxiliary plant.

The Effect of Agglomerate on the Working of a Blast-Furnace. K. V. Messerle and B. M. Nosovitskiy. (Metallurg, 1938, No. 11, pp. 48–56). (In Russian). The authors describe experience at the Kirov and Makeevka Ironworks, giving the characteristics of the agglomerate, iron ore and coke used. They state that the addition of agglomerate (up to 58%) increased the output capacity of the blast-furnace, while at the same time the fuel consumption was progressively decreased. This resulted in a saving of 20% of the coke when using 58% of agglomerate. The addition of agglomerate improves the permeability of the stock and enables the blast to be increased. On the other hand, the use of agglomerate renders the operation of the furnace erratic in several respects, control being more difficult. Some methods of improving control are briefly considered.

The Reduction of Complex Chemical Compounds in Relation to Their Dissociation. A. S. Timashev. (Metallurg, 1939, No. 3, pp. 19–28). (In Russian). The reduction of ferric, ferroso-ferric and ferrous oxides with carbon monoxide at 500° C. was studied in an

apparatus in which a stream of carbon monoxide was passed over the heated oxides, provision being made for continuous and automatic recording of the temperature and the carbon dioxide content of the exit gases. Preliminary tests had shown that at the temperatures used, iron had a negligible catalytic effect on the reaction $2CO = CO_2 + C$. The reduction of the ferric oxide took place in two stages, the first being irreversible and leading to the formation of 100% of carbon dioxide ($3Fe_2O_3 + CO = 2Fe_3O_4 + CO_2$). The second stage corresponds to the reduction of the ferrosoferric oxide with the formation of a gas mixture of 47% of carbon dioxide and 53% of carbon monoxide. The ferrosoferric oxide is reduced directly to metallic iron ($Fe_3O_4 + 4CO = 3Fe + 4CO_2$). Under the experimental conditions the reduction of the ferrous oxide took place in two ways, namely, $FeO + CO = Fe + CO_2$ and also by a complex reaction, the net result of which is represented by the reaction $4FeO = Fe_3O_4 + Fe$. The whole of the ferrous oxide is decomposed at the beginning of the reduction, which afterwards consists of the reduction of the ferrosoferric oxide.

The Soda Process in Siderurgy. A. G. Lefebvre. (Revue Universelle des Mines, 1939, vol. 15, June, pp. 263–290). In the first part of this treatise on the desulphurisation of molten iron with soda ash as it leaves the blast-furnace or in the mixer, the author deals with the theory of the reactions in the light of laboratory tests and refers to the results of German and English investigations. In the second part he discusses the results actually obtained with full-scale plant, many of which he presents in tables and by three-dimensional diagrams.

The Slag-Preparation Plant of Mannesmannröhren-Werke, Abt. Heinrich-Bierwes-Hütte. K. Hupfer. (Stahl und Eisen, 1939, vol. 59, Aug. 10, pp. 920–924). The author describes the plant at the slag-preparation department of the Mannesmann Tube Company in Germany, where practically the entire production of slag is worked up into road metal, paving blocks, filling material, &c.

Possibilities of Utilising the Blast-Furnace Slags Arising from the Acid-Smelting Process. G. Mussgnug. (Stahl und Eisen, 1939, vol. 59, Aug. 3, pp. 889–894). The author discusses the results of investigations undertaken in Germany to examine the possibilities of making use of the large quantities of acid slag which are produced as a result of smelting low-grade ores. He finds that the slag can be used in some cases as a raw material in cement manufacture; it can also be added to the extent of 20–30% in the manufacture of Portland cement. Owing to the higher lime content, the increased fuel consumption for burning the cement and the increase in power required for grinding, the cost of the cement production is increased by 1.50–2.50 R.M. per ton. He also studies the application of acid slags for making refractory bricks; this can be done, but it requires special binding materials and a special hardening process.

Mineral Wool. J. R. Thoenen. (United States Bureau of Mines, 1939, June, Information Circular No. 6984R). The author has made a field survey of plants in the United States, where rock wool, slag wool and glass wool are manufactured, and he presents in this Information Circular data on the history of the industry, the capacity and operating technique of plants, the properties of the products and customers' specifications.

Anodes for the Electrowinning of Manganese. C. G. Fink and M. Kolodney. (Electrochemical Society, Sept. 1939, Preprint No. 5). The authors have developed a new anode, containing lead, tin and cobalt, which allows the electro-deposition of manganese from sulphate leach solutions without the undesirable formation of manganese dioxide. If a steel sheet is used as cathode it is not necessary to strip the metal deposited. The entire cathode, after deposition of the amount of manganese required, can be melted down for the production of ferro-manganese.

FOUNDRY PRACTICE

(Continued from pp. 192 A–196 A)

Relationship between the Quality of Iron and Steel Castings and the Nature of the Materials of the Melt. P. Bardenheuer. (Giesserei, 1939, vol. 26, Aug. 11, pp. 405–410). A German translation of a paper abstracted previously. (*See* p. 67 A).

The Addition of Limestone and Fluorspar in Cupola Practice. B. Osann. (Giessereipraxis, 1939, vol. 60, Apr. 23, pp. 161–163). The author explains the reactions which occur in a cupola when limestone with and without fluorspar is added to assist in the formation of a fluid slag. The effect of these additions on the desulphurisation is also discussed.

Laws Governing the Operation of the Cupola. M. Barigozzi (Institute of British Foundrymen (International Foundry Congress) London, June, 1939, Preprint No. 695). In this mathematical discussion the author develops and explains the use of four diagrams for solving problems relative to the coke consumption, rate of melting and blast volume in the working of a cupola.

The Latest Designs of Moulding Machines. W. Caspary. (Giesserei, 1939, vol. 26, July 14, pp. 361–364). Brief description with numerous illustrations are presented of some of the latest types of moulding machines now available in Germany.

Dry-Sand Practice for Steel Castings. C. J. Dadswell and T. R. Walker. (Engineer, 1939, vol. 167, June 16, pp. 749–752). A reproduction of a paper presented before the International Foundry Congress, London, June 12–17, 1939. (*See* p. 71 A).

Position of the Development of Centrifugal Casting in Germany. W. A. Geisler. (Institute of British Foundrymen (International Foundry Congress), London, June, 1939, Preprint No. 664). The author reviews the development during the last twenty years of centrifugal casting in Germany, giving brief descriptions and drawings of many of the processes.

The Fluidity of Steels in the Light of Recent Investigations. F. Eisermann. (Stahl und Eisen, 1939, vol. 59, July 27, pp. 857–861). After explaining the difference between viscosity and fluidity, the author makes a critical survey of the literature on fluidity tests with particular reference to the Ruff test.

PRODUCTION OF STEEL

(Continued from pp. 197 A–203 A)

The Position of Belgium as a Consumer and Producer of Special Steels. A. Duby. (Revue Universelles des Mines, 1939, vol. 15, June, pp. 253–263). In describing progress made in the production of special steels in Belgium, the author considers them in two classes, the low-alloy and the high-alloy steels. Under the former he pays special attention to a steel containing silicon 0·52%, chromium 0·65–0·68% and copper 0·52–0·65%, which can be made either by the open-hearth process or by a duplex process (basic-Bessemer/electric-furnace). This steel has a very high elastic limit and good weldability; it can be supplied in rolled sections, which should be normalised after rolling. Under the second category he deals with chromium-manganese, chromium-molybdenum, nickel-chromium and high-manganese steels.

The Profits of the American Steel Industry in the Period 1926 to 1938. J. W. Reichert. (Stahl und Eisen, 1939, vol. 59, June 22, pp. 731–735).

The Slope of the Open-Hearth Furnace Tap-Hole. P. V. Umrikhin. (Metallurg, 1939, No. 3, pp. 37–46). (In Russian). In the first part of the paper some observations on the tapping of a 35-ton acid open-hearth furnace are briefly recorded. These show how the inclination of the furnace bottom to the tap-hole and the depth of the bath affect the relative times during which metal and metal plus slag are tapped off, and how this in turn affects the number of slag inclusions. The greater part of the article is devoted to a description of laboratory experiments on a one-tenth scale model of the furnace hearth and tap-hole, using water and oil to represent the metal and the slag respectively. In a number of cases a concentrated zinc chloride solution was used in order to have the same ratio of specific gravities. The experiments showed that a 3° inclination of the tap-hole was insufficient and that a much better separation of the metal and the slag could be obtained by increasing this to 10°. In studying the actual pouring of the two liquids into a beaker representing the ladle, it was observed that undesirable breaking up of the oil (representing slag) into small droplets occurred when there was only a small quantity of oil and a large quantity of water coming from the tap-hole. As the quantity of oil became relatively larger, the drops into which it was broken up also became larger and were rapidly eliminated by rising out of the water (representing metal).

The Great Progress in the Open-Hearth Process of Steelmaking. S. F. Perin. (Revue Universelles des Mines, 1939, vol. 15, June,

pp. 244–252). The author reviews the history of steel making by the open-hearth process from 1865 to the present time.

The Behaviour and the Rôle of Manganese in the Basic Open-Hearth Process. S. Lifshits. (Stal, 1938, No. 12, pp. 7–12). (In Russian). On the basis of his own experimental results and those of other investigators, the author considers the concentration of manganese in the metal during the boil and its effect on the rate of carbon elimination, the effect of slag composition on the manganese content of the metal, the utilisation of the manganese originally present in the charge and the practice of making further additions of manganese ore. Towards the end of the boil, the normal rate of carbon elimination of about 0·004% per min. is obtained by keeping the manganese between 0·25 and 0·35%. The MnO/FeO ratio in the slag should be kept between 1·0 and 1·2, either by the addition of manganese ore and lime (the latter to combine with the silica in the manganese ore) or of lime if the ferrous oxide content is too high. For the best utilisation of the manganese, the amount of slag should be as small as possible. The use of manganese ore in the original charge is not recommended, neither is its addition in the initial stages of the boil.

Reactions Between Aluminium and Oxygen in Iron Melts. H. Wentrup and G. Hieber. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, July, pp. 15–20). A reproduction of an article which appeared in Technische Mitteilungen Krupp, Forschungsberichte, 1939, vol. 2, May, pp. 47–58. (*See* p. 144 A).

The Manufacture of Steel by the Basic-Bessemer/Electric Process at the Hoesch Steelworks, Dortmund (Germany). (Génie Civil, 1939, vol. 115, July 29, pp. 107–108). An abridged French translation of R. Graef's article in Stahl und Eisen, 1939, vol. 59, Mar. 30, pp. 385–395, in which a description is given of the process of refining basic Bessemer steel in an electric arc furnace. (*See* p. 16 A).

Technical Characteristics of Modern Electric Steel Furnaces. L. Aronov. (Stal, 1938, No. 12, pp. 39–42). (In Russian). A review of practice in Soviet Russia with some reference to recent developments abroad. During the period 1931 to 1936 the rating of electric-arc furnaces in Russia rose from 300 to 400 kVA. The author considers that the optimum rating should render the melting possible in 1½ to 2 hr. The use of graphitised electrodes in preference to carbon electrodes is recommended and the advantages of mechanical charging are referred to. The method at present in use in Russia is the Demag system, which involves the lifting of the roof with the electrodes.

Production and Properties of the Heat-Resisting Fe-Cr-Al Alloys with High Electrical Resistance. M. Pridantsev and N. Semenova. (Stal, 1939, No. 2, pp. 32–42). (In Russian). Research on the production of Chromal (up to 0·25% of carbon, up to 1·2% of silicon, 28–31%of chromium, 2·5–5·0% of aluminium) and Fechral (up to 0·25% of carbon, up to 1·2% of silicon, 13–15% of chromium,

3·5–5·0% of aluminium) at the laboratories of the Electrostal Works is described in detail, and some of the works production experience is also dealt with. The process of melting (use of slags, refining, methods of adding aluminium, non-metallic inclusions, ductility of metal obtained) was first studied in a H.F. induction furnace. The beneficial effects of low carbon and silicon contents and of additions of about 0·2% of titanium were observed. The casting of ingots was then investigated with reference to bottom pouring, use of chlorinated resin mould coatings and the filling of moulds with carbon tetrachloride. The cooling of ingots was studied in connection with their tendency to form concentric cracks. Ingots should be heated to 1200–1230° C. for forging or rolling. The removal of surface defects, the heat treatment, the drawing of wire, the effect of etching on brittleness, the effects of temperature, deformation and additions of nitrogen, titanium or zirconium on grain growth and the permissible service conditions for the iron-chromium-aluminium alloy were also investigated. It was found that only titanium additions had a grain-refining effect. The use of colloidal graphite with a suitable binding material as a lubricant is recommended for the drawing process.

The Structure of a Steel Ingot. H. Thyssen. (Revue Universelle des Mines, 1939, vol. 15, June, pp. 232–237). The author discusses the factors influencing the structure of a steel ingot and the effect of oxidising agents on the distribution of non-metallic inclusions.

Flakes in Steel *ShKh*-15. T. Ya. Duev and A. M. Stroganov. (Vestnik Metallopromyshlennosti, 1939, No. 1, pp. 49–58). (In Russian). The nominal composition of steel *ShKh*-15 is carbon 0·95–1·10%, silicon 0·15–0·35%, manganese 0·20–0·40%, sulphur 0·020% max., phosphorus 0·027% max., chromium 1·30% and nickel 0·20%. The investigation had for its object, in particular, the investigation of the behaviour of flakes during hot-working of the steel and the possibility of eliminating them. The work, which was carried out on a range of samples of the steel of different flakiness, included a study of the effect of the deformation in hot-rolling and forging on the "welding up" of the flakes, the difference between the mechanical properties of flaky and sound steel and finally the effect of flakes on the quality of ball-bearing rings made from the steel. It was found that flakes were not distributed uniformly throughout the ingots from one and the same heat of steel. Their distribution throughout individual ingots and, consequently, throughout the rolled products was also irregular. Although "welding-up" of the flakes occurred with heavy deformation in the hot state, their deleterious effect on the mechanical properties of the steel persisted, and was particularly marked in test-pieces taken parallel to the grain orientation.

REHEATING FURNACES

(Continued from pp. 82 A–83 A)

Modern Pit Design and Practice at Fairfield Works. E. A. Hawk and M. P. Burns. (Iron and Steel Engineer, 1939, vol. 16, June, pp. 32–40). The authors present a detailed description of the soaking-pit practice at the Fairfield Works of the Tennessee Coal, Iron and Railroad Co. The soaking-pits at these works consist of four rows of reversing regenerative pits, four rows of non-reversing, direct-fired pits and three rows of bottom-fired, non-reversing, recuperative pits.

Steel Mill Furnaces—II. Furnaces for Rod and Wire. M. H. Mawhinney. (Industrial Heating, 1939, vol. 6, Apr., pp. 324–334, 340; May, pp. 416–420). Continuation of a series of articles (*see* p. 82 A). In this part of his paper the author describes furnaces for heating rods, billets and wire, for patenting, annealing, galvanising, lead and tin coating and all processes involved in the manufacture of rod and wire.

Decarburization of Steel. M. H. Mawhinney. (Iron Age, 1939, vol. 144, July 20, pp. 27–30; July 27, pp. 38–42). In the first part of his paper the author considers the factors affecting the products of combustion, which in turn affect the degree of decarburisation of steel in open-fired furnaces with particular reference to soaking-pits. Open-fired furnaces are those in which the flue gases are in direct contact with the steel during heating and cooling. He finds that the conditions which will cause the minimum of decarburisation in such furnaces are: (1) A fuel low in hydrogen. (2) Positive pressure in the furnace. (3) As low a temperature as possible in most cases. (4) A supply of air slightly in excess of that required for perfect combustion. (5) Burners with good mixing characteristics. (6) The more the steel is reduced in section (*e.g.*, by rolling) after heating the less will be the decarburisation. (7) The time during which the steel is kept at high temperature should be as short as possible. In the concluding part the author presents and discusses data on the degree of decarburisation obtained in regenerative furnaces heated by coke-oven gas, by producer gas, by natural gas and by fuel oil.

FORGING, STAMPING AND DRAWING

(Continued from pp. 204 A–205 A)

Some Contributions of the Engineer towards Metallurgical Progress. P. Jump. (Proceedings of the Institution of Mechanical Engineers, 1938, vol. 140, pp. 581–587). In a historical review the author gives a number of examples illustrating how the devices of the engineer have assisted in the development of the art of forging.

The Testing of Sheet Metal Destined for Deep Drawing and Pressing. J. D. Jevons. (Sheet Metal Industries, 1939, vol. 13, June, pp. 775–780; July, pp. 901–906; Aug., pp. 1019–1025). In this series of articles the author describes a number of tests which have been used or proposed with the object of assessing the deep-drawing and pressing qualities of steel sheet, and he discusses their merits, defects and limitations. In the first part he deals with chemical analysis, microscopical examination, and hardness and bend tests. Under bend tests he describes a simple test devised by Siebel and Pomp, in which two parallel slots are cut near the centre of the specimen; the slotted part of the test-piece is then placed between a circular die and a clamping plate as in the Erichsen test, and a 20-mm. dia. roller with its axis at right angles to the slots is forced down on the strip of metal between the slots. The strip is extended and eventually fractures. The depth of the depression and the elongation are measured. This test is intermediate between the tensile and Erichsen tests, but it differs from the latter in that no compressive stresses are imposed on the specimen. The author then describes and discusses the merits of the Erichsen, Avery, Olsen, Amsler, Guillery, Jovignot, K.W.I. (Kaiser-Wilhelm-Institut) and A.E.G. (Allgemeine Elektricitäts-Gesellschaft) cupping tests for obtaining data on the drawing properties of steel sheet. He next compares by means of graphs the results of tests on the same sheet by these different methods and explains why some of the results are alike and others differ. He describes with diagrams the construction and operation of the A.E.G. cupping machine and the Hounsfield tensometer.

Drawing-Die Steels for the Cold-Drawing of Steel and Other Metals. H. Ahsmann. (Metallwirtschaft, 1939, vol. 18, July 28, pp. 656–660; Aug. 11, pp. 693–698; Aug. 18, pp. 711–714). After a review of the development of drawing-die steels, those used nowadays in practice are discussed in detail, in particular with regard to the choice of suitable steels for various purposes. The production of steels intended for drawing dies is fully described, with particular reference to the influence of various kinds of treat-

ment upon their properties as tools. The heat treatment and quenching of water-hardenable chromium-tungsten drawing-die steels are also described, with some practical examples.

Farmer Norton Wire-Drawing Machines. (Wire Industry, 1939, vol. 6, July, p. 485). Brief particulars are given of the "G.M." type of wire-drawing machine manufactured by Sir James Farmer Norton and Co., Ltd. These can be obtained as single-block machines, or with any number in sequence for multiple drawing. There is a separate motor for each block, with the result that clutches and their attendant worries are completely eliminated.

British Enterprise in Developing Rumanian Wire Rope Manufacture. (Wire Industry, 1939, vol. 6, July, pp. 457–458, 462). A brief account is given of the history of the Anglia Company, at Ploesti, Rumania, manufacturers of wire and manilla ropes. The company was founded in 1925 and has now developed to a productive capacity of 6000 tons per annum.

Wire Cleaning and Baking. (Iron Age, 1939, vol. 143, June 15, pp. 36–38). **Bethlehem Instals New Wire Cleaning and Baking Unit at Maryland Plant.** (Wire and Wire Products, 1939, vol. 14, July, pp. 376–377, 388). A brief illustrated description is given of the new wire-cleaning and baking plant at the Sparrows Point Works of the Bethlehem Steel Co. The new unit consists of two pickling tanks, a washing tank, a high-pressure spray tank, three lime tanks, a sulling rack and three flash bakers, with the necessary crane and conveyor equipment. With two bakers and seven racks in the pickling vats in constant use, the average baking time is 6 min. and the average pickling time 21 min.

ROLLING-MILL PRACTICE

(Continued from pp. 206 A–207 A)

Hot-Rolling Tests on a Carbon Steel and Three Alloy Steels. A. Pomp and W. Lueg. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 10, pp. 171–180). The authors report on a number of rolling tests in the temperature range 700–1200° C. on the relation between the roll pressure, the power consumption and the reduction in thickness of the rolled material. Four types of steel bars 20 × 20 mm. were tested : (*a*) Carbon 0·88% and copper 0·11%, (*b*) carbon 0·37%, copper 0·15%, chromium 1·05% and molybdenum 0·17%, (*c*) carbon 0·13%, copper 0·13% and nickel 3·74%, and (*d*) carbon 0·41%, copper 0·08%, nickel 0·20% and chromium 13·6%. They found that the forward slip and increase in width were dependent chiefly on the reduction in thickness, and to a much less extent on the rolling temperature. The only case in which the composition of the steel had any marked influence was that of steel (*d*), for which a greatly increased roll pressure was required. The forward slip and the increase in width were practically the same for all four compositions of steel.

Installing and Operating Grease-Lubricating Systems. L. W. Deutsch. (Iron and Steel Engineer, 1939, vol. 16, July, pp. 19–25). The author describes the development of centralised grease-lubricating systems for rolling mills and discusses some of the factors to be considered in the design and fitting of such installations.

Some Notes on Oiliness. D. Clayton. (Proceedings of the Institution of Mechanical Engineers, 1939, vol. 141, June, pp. 105–109). After considering some definitions of oiliness and the difference between oiliness and viscosity, the author refers to experiments designed to show the effect of pressure on viscosity. It has been found that oils with the lowest viscosity index are most sensitive to pressure, so that the effect of pressure is in the opposite order to that of temperature. He discusses next some experiments in the measurement of static and kinetic friction. In conclusion he stresses the need for further information on the properties of molecular films and on surface roughness, both as ordinarily understood and as molecular dimensions are approached.

The Determination of the Forward Slip in Hot-Rolling Tests. W. Lueg and A. Pomp. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 10, pp. 163–170). In this mathematical discussion the authors explain the corrections which should be used when applying formulæ for calculating the forward slip in cold-rolling to the process of hot-rolling. They

demonstrate that it is essential to take the contraction into account, and as an example they calculate the forward slip in the rolling of high-alloy steels at temperatures exceeding 1000° C.

Standard Permissible Variations in Dimensions and Workmanship for Hot-Rolled Carbon-Steel Bars. (American Iron and Steel Institute, Steel Products Manual, June, 1939). Tables are presented of the permissible tolerances in the dimensions of rolled steel bars of various sections in accordance with American manufacturers' standard practice.

Roll Designing for Steel Sections. C. Holzweiler and T. Dahl. (Stahl und Eisen, 1939, vol. 59, June 22, pp. 725–731). Continuation of a series of articles (*see* Journ. I. and S.I., 1937, No. II., p. 137 A). In a mathematical discussion the authors explain and apply their theories to the design of rolls for producing steel channels with particular reference to the German channel sections *NP* 8 and 10.

A.I. & S. Ltd. Kembla Works Continuous Sheet Bar and Billet Mill. J. A. Spence. (Broken Hill Proprietary Review, 1939, vol. 16, June, pp. 4–5). The author describes the motor-house and main driving equipment at the new continuous sheet bar and billet mills of Australian Iron and Steel, Ltd., at Port Kembla. (*See* p. 148 A).

Recent Progress in Rolling Mills with Special Reference to American Installations. E. Houbaer. (Revue Universelles des Mines, 1939, vol. 15, June, pp. 237–244). The author describes some of the new American mills for the rolling of plates, sheets and strip.

The Causes of "Roll-Marks" on Tinplate. R. Griffiths. (Iron and Steel Institute, 1939, this Journal, pp. 39 P–53 P). The defect arising in the production of tinplate known as "roll-marks" or "roll pick-up" is considered. The various contributing factors, such as method of working, roll camber and relative speeds of the rolls, are discussed. The ultimate cause of the defect is ascribed to particles of material picked up by the rolls from the sheets due to accelerated slip occurring locally between a roll and a sheet; the pressure and velocity of this slip is sufficient to cause the particles of the sheet to become heated and "tacky." The evidence in support of this contention is the recrystallised character of the streaks or particles on the sheets.

Four-High Mills for Strip Rolling. (Metal Industry, 1939, vol. 54, June 30, pp. 693–694). Some particulars are given of a number of cold strip mills seen under construction at the works of Davy and United Engineering Co., Ltd. The machinery comprises a four-stand continuous mill having rolls 7½ in. and 18 in. in dia. by 14 in. long, one additional single-stand mill of these dimensions, and another having rolls 8 in. and 20 in. in dia. by 18 in. long, all mills being of the four-high type. The tandem mill will be so arranged that it can be used as a four-stand tandem mill or as a three-stand tandem and one single stand, and it is, therefore, equipped with two reels, one following the third and another following the fourth stand. The

mills will be driven through combination drive and pinion stand from main mill motors of 250 h.p., 500–800 r.p.m., except the 8 in. and 20 in. by 18 in. single-stand mill which has a 400-h.p. motor.

A brief description is also given of a 12,000-ton forging press and a 15,000-ton bending press which are also in course of construction at the same works.

Richard Thomas and Co., Ltd., Instals First Wide Strip Mill in United Kingdom. T. J. Ess and J. D. Kelly. (Iron and Steel Engineer, 1939, vol. 16, July, pp. R.T. 1–15). The authors present a comprehensive description, with numerous illustrations, plans and tables, of the new hot and cold strip mill at the Ebbw Vale Works of Richard Thomas and Co., Ltd.

Construction and Operation of the First German Wide-Strip Mill. F. Winterhoff. (Metallurgia, 1939, vol. 20, June, pp. 77–78). An abridged English translation of an article which appeared in Stahl und Eisen, 1938, vol. 58, Nov. 3, pp. 1225–1237. (*See* Journ. I. and S.I., 1939, No. I., p. 96 A).

Tension Control. C. M. Hathaway and F. Mohler. (Steel, 1939, vol. 105, July 17, pp. 63–67). A description is given of an electrical instrument used to measure and control the tension on steel strip as it passes from one roll stand to another. The instrument, called a tensiometer, will also indicate any difference in tension at each side of the strip; this is important, as this factor shows whether the thickness is constant across the strip. The device consists of a roller so placed as to deflect the strip a small distance above the normal pass line. As the strip passes over it a force is exerted on the roller at right angles to the normal pass line, and this force is proportional to the total tension on the strip. Each end of this roller is mounted in self-aligning bearings on a stiff cantilever beam, and the deflection of each beam is measured by electrical means, the indicator being calibrated to show changes in tension.

Electricity's Rôle in the Irvin Works. F. Mohler. (Iron Age, 1939, vol. 144, July 27, pp. 32–36). The author describes the scheme and layout of the electrical controls at the 80-in. strip mill at the Irvin Works of the Carnegie-Illinois Steel Corporation.

The Effect of the Reduction Sequence in Cold-Rolling on the Mechanical Properties of Stainless Steel. V. P. Severdenko. (Metallurg, 1939, No. 2, pp. 92–93). (In Russian). Tests on a number of stainless steels of approximately 18/8 composition showed that a reduction in the number of passes for one and the same total reduction lowered the tensile strength and increased the elongation as compared with the values obtained when using a larger number of passes.

Works of the National Tube Company. (Iron and Coal Trades Review, 1939, vol. 138, June 30, pp. 1115–1116). A brief illustrated description is given of the plant and products of the National Tube Co., Pittsburgh, a subsidiary of the United States Steel Corporation. This company is the largest tube manufacturer in the world, and is capable of producing over 2,000,000 tons per annum in finished tube.

The range of sizes is from $\frac{1}{8}$ in. to 96 in. in dia. The plants at the National, Gary, Ellwood and Lorain works are dealt with separately.

Electricity—What it Controls in Modern Steel Rolling. J. R. Morgan. (Sheet Metal Industries, 1939, vol. 13, July, pp. 874–878). The author describes the functions of the electrical equipment at the rolling mills at the Ebbw Vale Works of Richard Thomas and Co., Ltd.

Speed Control by Voltage Control. R. A. Geuder. (Iron and Steel Engineer, 1939, vol. 16, July, pp. 34–38). The author discusses the fundamental principles of the control of voltage as a means of controlling the speed of the electric motors used in rolling mills.

Protection of Branch Circuits for Auxiliary Motors. W. Deans. (Iron and Steel Engineer, 1939, vol. 16, June, pp. 17–25). The author describes and explains some circuits used for auxiliary motors in rolling mills, and methods of protecting them.

Pin-Hole Detector. G. A. Caldwell. (Iron Age, 1939, vol. 143, June 29, pp. 26–28). The author describes and illustrates an electric instrument used in conjunction with a strip mill. This instrument is capable of detecting pin-holes down to $\frac{1}{64}$ in. in dia. when the strip is passing the instrument at any speed between 100 and 1000 ft. per min. The instrument consists essentially of a source of light in the form of several electric lamps with suitable focusing lenses mounted about 1 in. above a number of photo-electric cells sufficient to cover the width of the strip The strip passes between the source of light and the cell. When a pin-hole in the strip passes over the cell, the flow of current through it is affected, and this change is amplified by a suitable circuit of valves and rectifiers, so that an electrical impulse or signal is produced. It is usual to use a marking machine, operated by a solenoid, in conjunction with the detector; the former leaves a mark on the strip close to the hole. Finally, an automatic classifier can also be connected to the detector and marker; the classifier is placed after the flying shears, and its function is to separate the marked sheets on to a different pile.

Rolling-Mill Control. (Steel, 1939, vol. 27, July 3, pp. 52–54). In this paper the importance of instrumentation for the satisfactory working of modern high-speed rolling mills is stressed, and brief descriptions are given of electric tachometers and an "electronic instagraph" which is an optical instrument for measuring and automatically recording the temperature of a moving body passing across the field of the sighting tube.

HEAT TREATMENT

(Continued from pp. 208 A–210 A)

Bright Hardening of Small Parts. (Iron Age, 1939, vol. 144, July 20, pp. 32–33). A brief description is given of a small unit for the bright-hardening of small parts. An advantage of this unit is that the parts are simply put in the furnace loose on a tray, so that no material or labour is required for packing. The furnace atmosphere used is anhydrous ammonia, and a sealing curtain of carbon-monoxide/carbon-dioxide passes upwards over the opening when the door is lifted. In order to quench the parts, a chute is fitted through the floor at the front of the furnace, the lower end of which is below the surface of the quenching medium; by tilting the furnace the parts can therefore be dropped into the bath without being exposed to the outside atmosphere.

Reducing Atmospheres from the Combustion of Gas. L. O. Howell. (Heat Treating and Forging, 1939, vol. 25, June, pp. 303–305, 308). The author reports on some of the research work carried out by the Committee on Industrial Gas Research of the American Gas Association on the combustion of gas under high-temperature conditions. After referring briefly to previous work by this committee, the author presents some results of laboratory investigations of the combustion of natural gas and of coke-oven gas with insufficient air. These investigations were made in a furnace 2 in. in dia. by 48 in. long with a burner at one end and a series of ports along it for taking temperature readings and samples of gas for analysis. He presents curves showing the effect of temperature and the proportion of air on the carbon-monoxide/carbon-dioxide ratio in the burnt gases, as well as the minimum distance from the burner at which the maximum temperature is obtained at different rates of heat input.

The Status of Prepared Atmospheres in the Heat Treatment of Steel. B. W. Gonser. (American Gas Association, Mar., 1939: Heat Treating and Forging, 1939, vol. 27, May, pp. 247–251; June, pp. 306–308). The author discusses the use of different gases in heat-treatment furnaces and reproduces a number of graphs which show the relation between the decarburisation or carburisation, as determined by change in weight, and the percentage of carbon in the steel using different furnace atmospheres at different temperatures. He considers the means of purifying the gas mixtures, and points out that suppliers of heat-treatment furnaces now include equipment for removing both moisture and carbon dioxide with the furnace installations.

An Annealing Furnace with Hot Stacking of the Sheets. W. Schoeck. (Stahl und Eisen, 1939, vol. 59, July 27, p. 867). The author describes a new accessory equipment which can be fitted at the discharge end of a continuous annealing furnace. This consists of a platform lined with refractory bricks which can be raised and lowered. As the sheets in the red-hot state come to the end of the furnace conveyor they are automatically stacked on to the platform. When a sufficient weight of sheets is collected, the platform can be rapidly lowered on to a bogie and a cover put over the stack so that the sheets can cool slowly. The loaded platform can be replaced by an empty one so quickly that the discharge of the sheets from the furnace is not interrupted.

Recirculating Air Heating for Industrial Furnaces. E. Stephenson, jun. (Heat Treating and Forging, 1939, vol. 25, June, pp. 299–302, 308). The author discusses the principles to be applied in the design and construction of heat-treatment furnaces in which the charge is heated by hot air circulated by fans.

Commercial Heat-Treating Firm Modernizes Plant. A. M. Cox. (Heat Treating and Forging, 1939, vol. 27, May, pp. 224–226). The author describes the plant and processes used by the Pittsburgh Commercial Heat Treating Co., for the heat treatment of gears, pinions, dies, tools, springs and shafts. The processes include that of Chapmanising in which the nitrogen is obtained from cracked ammonia gas.

Hardening-Drawing Axles Automatically. L. C. Powell. (Iron Age, 1939, vol. 144, July 6, pp. 44–46). A brief description is given of the hardening and tempering equipment used by an American manufacturer for the heat treatment of automobile axles. The operation takes 3½ hr. and is completely automatic from the time the axle is placed in the first furnace, which is heated by gas passing through horizontal radiant tubes. After leaving this furnace the axles pass to the oil quenching-bath and from there to the tempering furnace. The full length of the whole plant is about 60 ft. and it has a capacity of 700 lb. per hr. or about 1500 axles per 24-hr. day.

The Hardening of Steel with Particular Reference to the Effect of the Quenching Medium upon the Hardening Process. A. Rose. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 11, pp. 181–196). The author investigates the process of hardening steels using different quenching media. He finds that the cooling properties of liquids are governed by three factors: The formation of a covering layer or film of vapour, boiling and convection. The temperature ranges within which these processes occur vary with different quenching media. The peculiarities of water as a quenching medium are its high rate of cooling and the instability of the film of steam. There is a marked difference in the behaviour of mineral and vegetable oils. The cooling rates are higher for the latter and the boiling is steady over a wide temperature range. The differences between individual mineral

oils are due more to differences in physical properties than to their chemical structure. There is a gap between the quenching properties of water and those of oil, and this can be bridged by the use of emulsions, pectin and water-glass. The author reproduces a number of cooling curves which demonstrate that by varying the strength of a water-glass solution its cooling properties can be varied over a wide range. He also takes the appropriate coefficient of thermal conductivity for the quenching medium into account when evaluating quenching factors for water, oil and air, and shows, by means of a comprehensive table in which the results of his own and other investigators' tests are compared, that media can be prepared to cover the whole range of quenching at from 0 to 15,000 kg.cal. per sq. m. per hr.

Stepped Quenching and Multiple Tempering of High-Speed Steel. A. P. Gulyaev and P. I. Podberezkiy. (Metallurg, 1939, No. 2, pp. 70–75). (In Russian). Specimens of steel containing 0·82% of carbon, 18·71% of tungsten, 4·19% of chromium, 0·62% of vanadium, 0·33% of manganese, 0·21% of silicon, 0·012% of phosphorus, 0·016% of sulphur and 0·10% of nickel were subjected to stepped quenching from 1280° C. to " ageing temperatures " of 500°, 600°, 625°, 650° and 700° C., at which they were held for from 10 min. to 3 hr. prior to cooling and multiple tempering at 560–575° C. for periods of 1 hr. The effects of such heat treatments on the hardness and microstructure of the steel and finally on the properties of milling cutters made from it were investigated. Some data were also obtained by dilatometric analysis. Ageing at the intermediate temperatures caused a slight increase (of 1–2 Rockwell units) in hardness, due to the precipitation of carbides, which was followed, at the higher temperatures, by a rapid drop in hardness. Incompletely aged steel showed an increase in hardness during subsequent multiple annealing. Microscopic examination indicated that ageing caused the decomposition of austenite into troostite at the grain boundaries. The temperature and duration of ageing during quenching affect the position of the secondary martensite point in tempering, this point rising with increased ageing. The practical tests confirmed the advantages (such as reduced distortion and improved wear resistance) of stepped quenching.

Making Sucker Rods. R. M. Pease. (Steel, 1939, vol. 105, July 10, pp. 64–67). A description is given of the processes of manufacturing and heat treating " sucker rods." This is the name given to the rods used for transmitting the power from the engine at the top of an oil well to the pump at the bottom. The heat treatment of these rods was described in more detail in Steel, 1939, vol. 104, May 20, pp. 54–56. (*See* p. 153 A.)

WELDING AND CUTTING

(Continued from pp. 211 A–213 A)

Third Report of the Welding Research Committee. (Proceedings of the Institution of Mechanical Engineers, 1938, vol. 140, pp. 521–579: Engineering, 1939, vol. 147, May 19, pp. 602–604; May 26, pp. 635–637). In this Report of the Welding Research Committee which was appointed in 1930 by the Institution of Mechanical Engineers, an account is presented of the investigation of the strength of welds in steel boiler drums and other pressure vessels with particular reference to repeated-stress tests.

The Production of Fusion-Welded Gas, Water and Steam Tubes by the Fretz-Moon Process. P. Inden. (Apparatebau, 1939, vol. 51, June 9, pp. 114–116). The author describes the Fretz-Moon process of tube manufacture employed at a works of the Thyssen group for the manufacture of gas, water and steam tubes from 10 to 76 mm. in outside diameter. This article also appeared in Zeitschrift des Vereines deutscher Ingenieure, 1938, vol. 82, Dec. 24, pp. 1489–1491. (*See* Journ. I. and S.I., 1939, No. I., p. 164 A).

Automatic Arc Welding without Mechanical Aid. G. Hafergut. (Zeitschrift des Vereines deutscher Ingenieure, 1939, vol. 83, Aug. 19, pp. 951–952). The author describes a simple technique for making long, horizontal, or nearly horizontal, butt or fillet welds automatically, using coated electrodes, without requiring any machinery for moving the electrode over the work. To make a butt weld the electrode is laid along the groove formed by the two bevelled edges of the plates, with one end protruding beyond the joint, and one pole of the transformer is connected to this end; the other pole is connected to the work in the usual way. The only additional equipment required consists of one or more bars of copper or aluminium and some strips of brown paper. A groove is cut in one face of the copper or aluminium bar, which is placed over the joint with a strip of paper between the electrode and the bar; the groove helps to keep the electrode in position and is sufficiently large to leave two small air spaces, one along each side of the electrode. The arc is struck by passing a piece of metal or carbon across the free end of the electrode and the work, and, as the metal melts, it burns away the paper strip, thus consuming the oxygen in the air spaces and preventing the formation of oxides. Sheets down to 1 mm. thick have been satisfactorily welded by this process. The economy of the process depends upon the nature and amount of the welding required. It has been found to save both time and labour, as one unskilled man can do as much welding

by this process as two or even three skilled welders could do by hand.

Arc Welding the Stainless Steels. E. J. Brady. (Welding Journal, 1939, vol. 18, July, pp. 410–412). The author classifies stainless steels into the martensitic, ferritic and austenitic groups and summarises and correlates the latest information and experience as to their welding properties and the correct composition of the electrodes for welding them.

The Ignitron—A Precision Switch for Resistance Welding Control. H. de B. Knight. (Welding Industry, 1939, vol. 7, Mar., pp. 54–56). The author describes a special type of mercury arc-rectifier, known as the "Ignitron," in which the arc is started by means of a special igniter and in which there are no moving parts. The igniter enables precise control of the arc to be obtained, a feature which, together with the known ability of the mercury rectifier to give very high peak currents, makes it particularly suitable for the control of resistance-welding equipment. In addition it has a low voltage drop and hence a high efficiency. The glass-bulb and the steel-jacket types are illustrated and diagrams of connections are given.

Heat Control of Resistance Welding Machines by Means of Steel Ignitrons. B. G. Higgins. (Welding Industry, 1939, vol. 7, Aug., pp. 264–269). The author describes in detail the steel ignitron referred to in the preceding abstract and its application to the control of spot and seam welding.

Flash-Butt Welding of Alloy Steel Tubes. W. Denker. (Welding Industry, 1939, vol. 7, July, pp. 209–211 : Welding Journal, 1939, vol. 18, June, pp. 372–373). An abridged English translation is presented of an article which appeared in Stahl und Eisen, 1939, vol. 59, Mar. 30, pp. 396–398. (*See* p. 23 A).

Light-Weight Box Cars. (Steel, 1939, vol. 104, June 26, pp. 44–45, 63 ; July 3, pp. 61–64, 73). Some particulars are given of the steel sections and methods of welding employed by the Pullman-Standard Car Manufacturing Co. of Michigan City for the manufacture of railway box-wagons. These methods have resulted in a great saving in weight.

The Soldering and the Brazing of Alloy Steels. P. Schafmeister and H. Schottky. (Technische Mitteilungen Krupp, Technische Berichte, 1939, vol. 7, July, pp. 91–96). The authors describe the properties of soldered and brazed joints in alloy steels, giving particulars of the solders and brazing metals used. They deal in particular with the problem of cracks in both soldered and brazed joints ; these cracks also penetrate into the parent metal and they occur when the part is under tensile stress and in contact with molten brazing metal or solder, even when the melting point of the solder (*e.g.*, tin-lead-bismuth-cadmium alloy) is only 60° C.

Weldability Tests. (Revue de la Soudure Autogène, 1939, vol. 31, June, pp. 702–705). A review is presented of various recognised

methods of testing the welding properties of steel. These methods include the specifications of the French navy, French regulations for bridges and structures, German Engineering Standard DIN 4100, German State Railway specifications, German electrode specifications, and English and the Metropolitan-Vickers specifications.

Tests Using Methods of Determining the Capacity for Deformation of Multi-Run Welds in Dead Mild Steel. K. L. Zeyen. (Technische Mitteilungen Krupp, Technische Berichte, 1939, vol. 7, July, pp. 96–120). The author describes an investigation by means of tensile, bend and notched-bar impact tests of the quality of multi-run welds in mild steel made by the autogenous and electric methods. The results confirmed the conclusion of previous investigators that the chemical composition (especially the nitrogen and oxygen contents) has a most important bearing on the mechanical properties of the welded article. Notched-bar impact tests with the base of the notch in the weld metal were made over a temperature range of $-70°$ to $+400°$ C. The author found that in autogenous welds made with non-austenitic welding rods a definite relationship existed between the chemical composition of the parent metal and the notch-sensitivity of the weld and the sensitivity to ageing, for he noted that the greater the content of alloying elements, especially silicon and manganese, the better were the test results. Annealing further improved the results, and normalising was still more beneficial. In the case of electrically welded joints made with non-austenitic electrodes on unheat-treated specimens, he found that the higher the nitrogen content of the parent metal the better were the notched-bar impact values. Heat treatment of electrically welded material low in nitrogen improved the impact test results even at very low temperatures. On the other hand, the impact values of welds high in nitrogen were lowered by annealing, and, when tested at low temperatures, they were also lowered by normalising, but when tested at higher temperatures, normalising sometimes had a beneficial effect. The impact values of welds made with austenitic electrodes or welding rods were better than those obtained when non-austenitic rods were used; in these tests annealing improved the results in most cases, whilst normalising always lowered the values. It was found that better impact values were obtained on welds made with a heat-resisting steel (nickel about 20% and chromium 25%) than with a stainless steel (nickel 8–10%, chromium 18–20%), and that this also applied when the manganese content of the parent metal was normal or high.

Tensile tests with the stress longitudinal to the weld on gas-welded and electrically welded specimens using rods of different composition produced remarkably different results. Pulsating fatigue tests showed that both the thickness of the weld metal and the nature of the intermediate layer between the parent metal and the weld metal had a marked influence on these results. Gas welding and electric welding with coated electrodes gave better pulsating-fatigue-test results than when bare, dipped or cored

electrodes were used. Fatigue tests on specimens welded with coated electrodes with the welds left unmachined showed that subsequent heat treatment lowered the fatigue strength. In conclusion the author points out that the causes of the deleterious effect which normalising sometimes has on a welded joint are : (1) A change in the form of the nitrogen in nitrogen-rich welds ; (2) an increase in the grain size when coated electrodes are used ; and (3) precipitation of the carbide when austenitic electrodes are used.

The Effect of Certain Factors on the Izod Value of Weld Metal. L. W. Schuster. (Proceedings of the Institution of Mechanical Engineers, 1938, vol. 140, pp. 453–519). This research was carried out to obtain data on the application of the Izod test to non-alloyed weld metal. In general it was found that a good-grade refined weld metal, owing to its fine grain-structure, behaves in the Izod test much as an alloy steel hardened and tempered at, say, 650° C. The extent to which the Izod value of such a weld is lowered by the presence of unrefined metal of any given depth was studied. To allow the start of the crack to be nearer than usual to the surface of the specimen, experiments were made on specimens with the notch depth reduced from 2 to 1 mm., the height of specimen required to give an equivalent result being determined for a good-grade refined metal. Results from specimens, both longitudinal and transverse, with notches at the various sides were compared, also the results from square and round specimens. A form of representative all-weld-metal specimen was devised which allowed the Izod results to be more truly representative of a test on a welded joint. The effect on the test result of varying the plate thickness, as well as of the interval of time between the laying of the runs, was studied, also the effect of constraining the joint during welding, some additional comparative experiments being made on rigidly constrained massive welds, chilled with water during deposition. The effect of a low-temperature annealing treatment on the Izod value was determined for several good-grade metals. To obtain data on the liability for results to vary according to the temperature of the test-house, tests were made on chosen grades of weld metal, completely refined and completely unrefined, in each of two states of heat treatment, and it was found that for good fine-grained metal with a nitrogen content not exceeding 0·020%, a decrease in test temperature from 100° to 32° F. caused no falling-off in the Izod figure for specimens in the condition as welded.

Determination of the Limiting Size of Defects Detectable in the X-Ray Examination of Welded Joints. M. S. Ovoshchnikov. (Zavodskaya Laboratoriya, 1939, No. 3, pp. 299–303). (In Russian). Results are given showing how the detectability of gas and slag inclusions, cracks and insufficient penetration in welded steel joints compares with that of standards (wires of different thickness, metal strips of different thickness with and without holes). The effect of the time of exposure and the rating of the X-ray tube were also

studied. Curves co-ordinating the different variables are given and a number of radiographs of welds taken in different directions are reproduced.

The Radiographic Checking of Welded Structures. F. Campus and H. Louis. (Revue Universelle des Mines, 1939, vol. 15, July, pp. 345–360). In the introduction the first-named author summarises the question of the checking of welded structures and refers to his earlier conclusion that radiographic examination alone is not always sufficient and in difficult cases should be supplemented by other testing methods. He then describes the principles underlying the development of a travelling X-ray laboratory. In the second part the second author discusses the principles of checking structures by the use of X-rays and means of generating the rays, and gives consideration to the choice of the variable factors entering into the making of X-ray exposures, the films used and protection against secondary radiation. He then comments on the principal defects found in welds and describes the travelling X-ray laboratory.

Tentative French Specifications for Testing the Weldability (Gas and Spot Welding) of Steels for Aircraft Construction. (Welding Journal, 1939, vol. 18, July, pp. 428–431). An abridged English translation of the specification for testing the weldability of steel for aircraft which was proposed by a sub-committee appointed by the Comité de Normalisation de la Soudure. The full specification appeared in Revue de la Soudure Autogène, 1939, vol. 31, Apr., pp. 654–660. (*See* p. 97 A).

Oxygen Cutting of Steel. Part I. Mechanical Properties and Metallurgy. W. Sparagen and G. E. Claussen. (Welding Journal, 1939, vol. 18, July, Supplement, pp. 217–248). The authors review the literature to January 1939 by presenting in separate sections summaries of the information available on the properties of plain carbon and alloy steels which have been cut by the autogenous process. The metallurgical characteristics of the surface left by the flame are also dealt with. A bibliography of 153 references is included.

The Effect of Flame Cutting on Steel. (International Acetylene Association, Oxy-Acetylene Committee Publications, Section VIII., 1938–1939). In this publication a review is presented of the information obtained from numerous investigations of the effects of oxy-acetylene cutting on steel. The review is divided into the following sections: (*a*) Low and medium carbon steels; (*b*) higher carbon and alloy steels; (*c*) the flame-cutting process; (*d*) the depth of the affected zone; (*e*) the "cutability" of steels; (*f*) mechanical effects; (*g*) chemical effects; (*h*) preheating and post-annealing and (*i*) flame-softening. The test data are presented in an appendix.

CLEANING AND PICKLING OF METALS

(Continued from pp. 158 A–159 A)

Cleaning of Metals. C. C. Hermann and R. W. Mitchell. (Iron Age, 1939, vol. 144, July 6, pp. 48–50). The authors describe some pickling baths and labour-saving equipment used at small pickling plants.

Electrolytic Cleaning. W. F. Hall. (Steel, 1939, vol. 105, July 10, pp. 54–56). The author outlines the process of the electrolytic cleaning of coils of wide steel strip prior to plating. The essential feature of the cleaning plant is the tank, which may be over 60 ft. long, containing an alkaline cleaning solution and specially designed large-surface electrodes or grids in sections extending the entire length of the tank. The strip passes through the bath at a predetermined depth between the electrodes.

Modern Methods of Acid Pickling. R. Saxton. (Sheet Metal Industries, 1939, vol. 13, June, pp. 763–764). The author describes briefly some modern methods of pickling steel sheet, explaining the composition of the solutions used, the reactions which take place and the functions of inhibitors.

Practical Aspects of Pickling. P. Dickens. (Iron and Coal Trades Review, 1939, vol. 138, June 16, p. 1042; June 23, p. 1072). An abridged German translation is given of an article which appeared in Stahl und Eisen, 1939, vol. 59, Mar. 23, pp. 364–370, in which the author describes a laboratory investigation of the effect of ferrous sulphate on the rates of solution of iron and mill scale in sulphuric acid. (*See* p. 28 A).

A Talk on the Use of Inhibitors. (Wire Industry, 1939, vol. 6, Apr., pp. 253–254). An explanation is given of the purpose of the addition of inhibitors to the acid solutions in pickling tanks, and this is followed by brief descriptions of the "starvation" and "endurance" tests of the efficiency of inhibitors. In the former, the procedure is to reduce the concentration of the inhibitor and determine the increase in metal loss which follows each reduction. The latter is a method of determining the life of the inhibitor in the pickling medium. Some particulars are given of the properties of two inhibitors known as "Hibitite A" and "Hibitite TR."

Some Further Comments on the Use of Inhibitors. A. Keller and K. A. Bohacek. (Wire Industry, 1939, vol. 6, June, pp. 383–384). The authors explain the reactions occurring in a pickling tank which cause the evolution of hydrogen, and give some particulars of "Inhibitor Adacid," which is claimed to be an effective inhibitor even at temperatures as high as 180–200° F.

Electrolytic Pickling of Stainless Steel Strip. J. D. Geiser. (Blast Furnace and Steel Plant, 1939, vol. 27, Mar., pp. 258–261, 270; Apr., pp. 352–353, 359–360; May, pp. 487, 503, 506, 520; June, pp. 598–599). In Part I. of this series the author describes the nature of the scale formed on stainless steel strip of different analyses by the annealing process, and then gives a general description of some continuous electrolytic pickling units used by two American companies. In Part II. he describes the plants used by these companies for the pickling of chromium and chromium-nickel steels, giving particulars of the solutions used and the acid and electricity consumptions. In Part III. he gives further details of the pickling plant with particular reference to the advantages and disadvantages of take-up blocks and pinch rolls for pulling the strip through the pickler. From his comparison, it is seen that pinch rolls are better for speeds up to about 50 ft. per min., whilst at higher speeds the direct pull by blocks is more satisfactory. In Part IV., which concludes the series, the author points out two factors tending to promote the rapid development and application of electrolytic pickling. The first is that the high rate of production in continuous strip mills has overtaken the rate at which the product can be pickled by ordinary methods unless a large capital sum is expended in a huge plant occupying a great deal of space. The second is the proposed enforcement, especially in Pennsylvania, of laws prohibiting the pollution of streams with acid. The use of the electrolytic pickling process will meet both these difficulties.

COATING OF METALS

(Continued from pp. 160 A–162 A)

Some Related Tasks of Eloxal Treatment and Hard-Chromium Plating. W. Müller. (Metallwirtschaft, 1939, vol. 18, Aug. 4, pp. 678–679). The author points out that the Eloxal treatment of aluminium and its alloys and hard-chromium plating of iron and steel have corresponding effects with regard to the improvement of the surface properties of the base metals.

Protection of Iron and its Alloys by Chemically and Electrolytically Deposited Coatings. R. Collée. (Revue Universelle des Mines, 1939, vol. 15, Aug., pp. 439–444). After an introduction, including a general classification of the various kinds of surface protection used for iron and its alloys, the following processes are reviewed : bronze coating, phosphatising and electrodeposition of nickel, cadmium and chromium.

Investigation and Development of the Electrolytic Surface Protection of Metals. H. Fischer. (Metallwirtschaft, 1939, vol. 18, July 14, pp. 613–616 ; July 21, 631–634). After a general review of the properties of electrolytically produced coatings and of their various applications with particular reference to zinc and cadmium coatings, the author discusses the protection of light alloys.

Porosity of Electrodeposited Silver on Steel. F. C. Mathers and L. I. Gilbertson. (Electrochemical Society, Sept. 1939, Preprint 4). The authors give an account of an investigation in which they determined the thickness of a coating of silver necessary for the protection of steel plate the surface of which was not specially prepared. Hot-rolled steel pickled in hot hydrochloric acid and tinplate from which the tin was removed by hot hydrochloric acid were used in their tests. They found that the porosity of the coating depends on its thickness, the condition of the surface of the base metal and the method of application. They concluded that steel plated in a bath with 0·0016–0·0040 in. of silver is suitable for the fabrication of industrial vessels, and that brush-plated steel with a coating 0·0001–0·0002 in. in thickness is suitable for containers of a temporary nature when great mechanical adherence is not required.

The Influence of the Base Material on the Quality of Electrodeposited Zinc Coatings. H. Dienbauer. (Berg- und Hüttenmännische Monatshefte, 1939, vol. 87, July, pp. 142–148). The author divides the material used for his investigation into two main groups, *viz.*, (1) non-siliconised, soft, hot-rolled open-hearth and electric-furnace steel sheets, and (2) the same materials in the form of cold-rolled and soft bright-annealed strip. The com-

position of the two steels is given. The electric-furnace steel contained an unusually high percentage of sulphur (0·038%). The electrodeposition was carried out in all cases in the same way, which is described in the paper. The corrosion resistance, porosity, hardness and adhesion of the coatings obtained were compared. The coatings deposited on the sheets proved to be more corrosion-resistant, although, before the electro-galvanising, the surface of the sheets had been much rougher than that of the strip. The smooth surface of the latter was effective, however, in so far that the coatings produced on the strip were less porous than those deposited on the sheets. The base material was found to have no influence on the hardness of the coatings. The adhesion of the coatings was greatest on the open-hearth steel strip and least on the strip made from electric-furnace steel. The two kinds of sheet gave intermediate values, those for open-hearth steel sheets being superior to those for electric-furnace steel. The unfavourable results obtained with the latter should, in the author's opinion, not be generalised, as they might be due to its high sulphur content.

On the Formation of White Rust on Galvanized Malleable Iron Fittings. F. Roll. (Metallwirtschaft, 1939, vol. 18, June 16, pp. 497–500). The author discusses the results of some experiments undertaken to ascertain the causes of a white or whitish-grey rust which appears on the galvanised surface of malleable iron fittings.

Modern Tin Plate Mill Features Irvin Works. (Industrial Heating, 1939, vol. 6, June, pp. 516–522). A description is given of the pickling, annealing and tinning plant and processes at the new tinplate mill at the Irvin Works of the Carnegie-Illinois Steel Corporation.

Electrotinning Strip Steel. J. S. Nachtman. (Steel, 1939, vol. 104, June 12, pp. 56–57, 81–82). The author gives a brief account of work which has now, after twelve years, led to the development of a continuous process for the electrolytic tinning of wide steel strip. In a modern plant using the process described, the weight of tin deposited can be controlled at any point between ¼ lb. and 3 lb. per basic box, 400 ft. of strip can be tinned in 1 min. and 96 tons of finished tinplate can be produced in an 8-hr. shift.

The Influence of the Steel-Base Composition on the Rate of Formation of Hydrogen-Swells in Canned-Fruit Tinplate Containers.—Part I. T. P. Hoar, T. N. Morris and W. B. Adam. (Iron and Steel Institute, 1939, this Journal, pp. 55 P–92 P). The rate of formation of hydrogen-swells in packs of typical British canned fruits has been studied in relation to the composition of the steel base of the tinplate by means of statistically-planned canning experiments. A " random sample " of the tinplate at present on the British market has been used, and each can has been analysed for sulphur, phosphorus and copper after forming a hydrogen-swell in storage under defined conditions. The corrosion rate and corrosion potential of the steel base of each can, in citric acid, have also been measured.

The results are correlated by the standard methods of statistical analysis. The present paper gives results for packs of blackcurrants, white cherries, gooseberries, loganberries, Pershore plums, raspberries and strawberries in double-lacquered cans. It is shown that the rate of formation of hydrogen-swells is significantly correlated with the corrosion rate of the steel base in citric acid. For several fruits the rate of swell-formation is lowest when the steel base has a high (up to 0·2%) copper content, while for others it is lowest when the phosphorus content is lowest; in general, it is suggested that the use of high-copper (0·16–0·22%), low-phosphorus (0·03–0·045%) steel should roughly double the expected life of packs of these fruits, on the average. Correlation between the composition variates themselves and the cathodic efficiency of the steel for hydrogen evolution have been discovered and are discussed in relation to the rate of formation of hydrogen-swells.

Oxide Film between Fired Ground-Coat Enamels and Iron. K. Kautz. (Journal of the American Ceramic Society, 1939, vol. 22, Aug., pp. 247–250). The author reports on some experiments made to obtain confirmation of the fact that a very thin film of ferrous oxide exists between the enamel coating and the base metal of enamelled-iron sheet. Specimens of enamelled sheet were heated in packs of four to 1600° F. until the enamel became tacky, and were pressed together at numerous places with tongs. When cold, the specimens were torn apart and the oxide film exposed was analysed and subjected to microscopic and X-ray examination. The results showed that α-iron, ferroso-ferric oxide and ferric oxide were present in the oxide film.

Observations on the Function of Adherence-Promoting Oxides in Ground-Coat Enamels. K. Kautz. (Journal of the American Ceramic Society, 1939, vol. 22, Aug., pp. 250–255). In order to obtain information on the relative adherence-promoting properties of certain oxides, the author prepared five enamels which contained, respectively, (*a*) no adherence-promoting oxides, (*b*) 0·5% of cobalt oxide (Co_3O_4), (*c*) 0·5% of nickel oxide, (*d*) 1·0% of manganese dioxide, and (*e*) all three of these oxides. The results showed that cobalt oxide promotes adherence, allows heavy films of iron oxide to form on the surface of the iron, and permits the more rapid penetration through the molten enamel of oxygen from the air. Nickel oxide behaves like cobalt oxide, but its effect is not so great. Manganese dioxide, on the other hand, does not increase the adherence, prevents the formation of any iron-oxide film and has only a slight effect upon the penetration of oxygen through the molten enamel.

Effect of Furnace Gases on Physical Properties of Wet-Process Cast-Iron Enamels. G. H. Spencer-Strong. (Journal of the American Ceramic Society, 1939, vol. 22, Aug., pp. 255–260). The author describes an investigation undertaken to determine the effect of firing lead-bearing and leadless enamels on cast iron in atmospheres of different compositions. His general conclusions are: (1) Water

vapour causes blisters in lead-bearing enamels, and blisters, specks and craters in leadless enamels applied without a ground-coat; it decreases the adherence in both cases. (2) Carbon dioxide causes lead-bearing enamels to become spongy and leadless enamels applied without ground-coats to become slightly spongy. (3) A deficiency of oxygen causes black specks to appear in leadless enamels applied without a ground-coat, but does not affect other types seriously; it does, however, appear to improve the adherence of leadless enamels applied over a ground-coat. (4) Water vapour seems to have a worse effect than that of any of the other gases studied. (5) When the castings are graphited before enamelling with lead-bearing enamels the tendency to form pin-holes is increased. (6) Leadless enamels applied over a ground-coat are affected less by the furnace atmosphere than are other types of enamels. (7) The characteristics of the iron itself play an important part in the behaviour of enamels in furnace atmospheres.

Modern Painting Practice for the Protection of Iron and Steel and Industrial Non-Ferrous Metals. D. G. Darroch. (Australasian Engineer, 1939, vol. 39, May 8, pp. 13–14, 49–51).—The author discusses the protective properties of paint materials, dealing with the subject under the following headings: (*a*) The more important rust-inhibitive pigments and their comparative values as primers; (*b*) the more recently developed paint pigments; (*c*) the media used in the so-called synthetic paints and enamels; (*d*) the methods of grinding and incorporating pigments and media; and (*e*) suggestions for the effective painting of metal surfaces.

The Protection of Metal Surfaces Against Marine Corrosion and Fouling. E. W. J. Mardles. (Institution of Naval Architects, Mar., 1939: Engineering, 1939, vol. 147, May 5, pp. 542–544). The author gives a short description of work carried out for the Air Ministry over many years on the protection of steel and light alloys, and some of the main conclusions derived from data obtained by observations on service machines and from tests on painted specimens subjected to the action of the tide in home and in tropical waters.

PROPERTIES AND TESTS

(Continued from pp. 214 A–227 A)

The Calculation of the Elongation on Fracture of Alloy Steel Specimens of Different Length. A. Krisch. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 12, pp. 197–200). The author constructs a conversion chart for calculating the elongation on fracture of specimens ranging in length from five to ten times the diameter, using the reduction in area. He tests the validity of the chart by comparison with the results of tests on 817 specimens of chromium-nickel, chromium-molybdenum and chromium-nickel-molybdenum steels and finds that they are in good agreement.

The Behaviour of Steels under Alternating Tensile Stress on Heating. M. Hempel and F. Ardelt. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 7, pp. 115–132). The authors describe an investigation of the elongation and fatigue strength of steel at 500° C. Three types of steel were tested, (*a*) an annealed mild steel containing carbon 0·58%, (*b*) a steel containing carbon 0·14% and molybdenum 0·51%, and (*c*) a steel containing carbon 0·56%, chromium 15·5%, nickel 13·3% and tungsten 2·02%. The tests were made in a machine capable of applying static tensile and compressive stresses of up to 60 tons, or alternating stresses of up to 40 tons, and the mean stress could be varied. A special device was fitted with which the rate of elongation could be determined with an accuracy of $\pm 0{\cdot}5 \times 10^{-4}\%$ per hr. The time-elongation curves obtained were of similar shape in all cases, and these showed that the rate of elongation was rapid during the first hour of the test, after which it decreased. From the data obtained curves were plotted showing the relationships between the total and permanent elongations and the rates of elongation at different mean stresses at constant maximum tensile and compressive stresses; these curves show that when the mean stress is zero an elongation nevertheless takes place. In conclusion the authors study the fatigue strength curves in which the mean stress is plotted against the maximum stresses for the three qualities of steel at 500° C.

Effect of the Testing Conditions on the Elastic Limit of Dead Mild Steel. E. Siebel and S. Schwaigerer. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, July, pp. 37–51). The authors examine the influence of different conditions of testing on the elastic limit of soft steel. They are of the opinion that upper and lower elastic limits actually exist and are not just brought about by the conditions of testing. An increase in the rate at which the load is applied

raises the elastic limit, but an increase in this rate will only have a marked effect on the upper elastic limit when the rate exceeds 1 kg. per sq. mm. per sec. On the other hand, it requires only a very small increase in the rate of reduction of area to produce a marked effect on the lower elastic limit. In general the authors find that the usual type of tensile testing machine satisfactorily demonstrates the characteristics of the material tested and there is, therefore, no reason for departing from this type. In conclusion the authors examine the effect of the shape of the section of the test-piece and the condition of its surface, and they find that, provided that the stress is evenly distributed across the specimen, these factors do not affect the elastic limits.

The Effect of the Speed of Stretching and the Rate of Loading on the Yielding of Mild Steel. E. A. Davis. (Transactions of the American Society of Mechanical Engineers, 1938, vol. 60, pp. A-137–A-140). The author studies the factors affecting the upper and lower yield points of mild steel. He describes a machine in which the amount of increase of load per unit of time could be kept constant regardless of the rate of elongation, and reproduces stress-strain diagrams from the test data from four different shapes of specimens. He comes to the following conclusions regarding the behaviour of mild steel during the first stages of yielding : (1) The upper yield point is influenced by stress concentration and the speed of deformation. (2) Local yielding produces a condition equivalent to a stress concentration at the boundary of the yielded portion. An increase in stress due to this concentration causes a rapid strain rate which allows the load to drop in an ordinary testing machine. (3) In a constant-strain-rate test an upper yield point is obtained when the stress concentration due to the shape of the specimen is less than that caused by local yielding. If no upper yield point is obtained, the stress concentration due to the shape of the specimen is greater than that caused by local yielding. (4) The lower yield point is the load at which the strain rate produced by the high stress that develops due to local yielding becomes equal to the strain rate prescribed by the testing machine. (5) In the plastic region the stress can be raised or lowered at any time by changing the speed of deformation. (6) At any instant during the discontinuous yielding, the actual stress, strain and strain rate cannot be determined with the ordinary means of measurement. (7) Discontinuous or localised yielding seems to be an inherent characteristic of the structure of mild steel and takes place whether the load is increasing or decreasing. The amount of yield-point elongation varies with the stress at which it takes place.

Tensile Testing in the Manufacture of Wire. G. C. Stauffer. (Metals and Alloys, 1939, vol. 10, June, pp. 173–176). The author describes a tensile testing machine specially designed for testing wire of small diameter. This machine is of the vertical-inclination balance type. In it the lower end of the specimen of predetermined

length is pulled downwards at uniform speed by a motor-driven train of gears. The upper end is attached to a bar transmitting the pull to a dead-weight pendulum designed to give constant speed of pull, and a recording device is attached to the machine in such a way as to produce a stress-strain curve for the wire under test.

Properties of the Steel Wire Wrappings of a Rotary Converter which Have Been in Use for Many Years. K. Daeves. (Elektrotechnik und Maschinenbau, 1939, vol. 57, No. 15–16, pp. 211–213). The author reports on the results of tensile tests on some steel wire which had been used for twelve years for binding the armature of a rotary converter. The steel contained carbon 0·45%, silicon 0·13%, manganese 0·68%, phosphorus 0·024%, sulphur 0·023%, chromium 0·13%, and copper 0·12%. It was found that the yield point and tensile strength were greater than those required by the German Engineering Standards, whilst the elongation and reduction of area were considerably less than those required in new wire. The author discusses the application of such tests for the purpose of determining whether material is fit for further service.

The Elastic Behaviour of Polycrystalline Iron. H. Möller. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, July, pp. 59–62). The author calculates the elastic constants of a polycrystalline structure from the constants of its individual crystals. He compares the elongation of iron as determined by mechanical and by radiographic methods. Having proved the fallacy of the assumption that all the crystals in polycrystalline iron deform to the same degree under tensile stress, the author states that it is no longer possible to apply the mechanically-determined coefficients of elasticity when determining stresses by X-rays, and he therefore suggests using coefficients of elasticity evaluated from X-ray elongation measurements.

Locomotive Axle Testing. T. V. Buckwalter, O. J. Horger and W. C. Sanders. (Transactions of the American Society of Mechanical Engineers, 1938, vol. 60, pp. 335–345). The authors give a detailed description of a machine for making fatigue tests on locomotive driving axles up to 11½ in. in dia. They present the data obtained on testing a number of 2-in. and 11½-in. axles and show that the propagation of fatigue cracks is greatly retarded by surface-rolling that portion of the axle which carries the wheel.

The Behaviour of Specimens with Residual Stresses when Subject to Fatigue Stress. F. Wever and G. Martin. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 14, pp. 213–218). The authors report on an investigation made to determine whether locked or residual stresses in steel are affected by the application of fatigue stresses and, if so, to what extent. The residual stresses before and after application of the fatigue stress were determined by radiographic methods. The authors came to the general conclusion that the application of fatigue stresses does reduce the amount of residual stress in steel.

Simultaneous Effects of Corrosion and Abrupt Changes in Section on the Fatigue Strength of Steel. T. J. Dolan. (Transactions of the American Society of Mechanical Engineers, 1938, vol. 60, pp. A-141–A-148). The author describes an investigation of the effects of abrupt changes in section on the torsional- and bending-fatigue strength of steel SAE3140. Some of the tests were made in air and others under tap-water. He found that the effect of having a stream of water over the specimen was to reduce the fatigue strength, and that the relative effects of water and of changes in section varied greatly with the heat treatment to which the specimen had been subjected. His general conclusion respecting this steel was that corrosion causes a much greater reduction in the strength of specimens subjected to completely reversed cycles of bend stress than it does to those subjected to completely reversed cycles of torsional stress.

The Problem of Fatigue Fractures : Magnetic Powder Pictures and Fatigue Fracture Cracks. M. Hempel. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 9, pp. 147–162). The author investigates the formation and propagation of fatigue cracks in steel by subjecting specimens to alternating bend tests and examining them by the magnetic powder process. He presents data on the number of stress reversals required to start a crack, the number of reversals which produce fracture, the effect of the shape of the specimen, and the load applied. Steels of two compositions were tested, one containing carbon 0·05%, silicon 0·018% and manganese 0·33%, the other containing carbon 0·58%, silicon 0·18% and manganese 0·72% ; both solid and drilled specimens were used. The number of stress reversals applied after a crack had become visible by the magnetic powder process until the crack penetrates to a given depth is taken as a measure of the rate of fatigue crack propagation. The results obtained from both solid and drilled specimens show that the number of reversals required, using a load exceeding the fatigue strength of the specimen, to cause a crack to penetrate increasing depths up to 1 mm. increases fairly rapidly, but to reach greater depths the number of reversals increases at a decreasing rate. When the crack has nearly reached the centre of the specimen the process of fracture begins and a few hundred more reversals cause fracture. Tests on solid specimens showed that the length of crack increases at the square of the rate at which the depth increases. It is also established that the depth of the crack and the area of the fatigue fracture bear a definite relationship to the length of the crack on the surface of the specimen. In comparing tests results from solid and drilled specimens the author observes that under equal conditions a fatigue crack appears more quickly in the latter, whilst after becoming visible its rate of propagation is slower. By studying the ratio of the number of reversals required to produce a crack to the number required to fracture and the ratio of the area of the fatigue fracture to that of the cross-section of the specimen for solid and drilled specimens, the author

finds that the form of the specimen has a predominating effect greatly exceeding that of the amount of the load or the composition of the specimen; with solid specimens the crack was observed after 85–90% of the reversals required to fracture and with drilled specimens the crack was observed after 30–60% of the total reversals. The author concludes with a comparison of his findings with those obtained by other investigators.

Relation of Wahl Correction Factor to Fatigue Tests on Helical Compression Springs. F. P. Zimmerli. (Transactions of the American Society of Mechanical Engineers, 1938, vol. 60, pp. 43–44). The author presents the results of a series of fatigue tests on coil springs made from the same bundle of wire. The investigation was undertaken to test the validity of Wahl's correction factor for formulæ for determining the stresses in heavy, closely coiled, helical springs (*see* Journ. I. and S.I., 1930, No. II., p. 582). The results showed that springs of low index have a higher endurance limit than those of high index and the author is of the opinion the Wahl correction factors for such springs are too high.

Fatigue Problems in the Aircraft Industry. K. Arnstein and E. L. Shaw. (Metals and Alloys, 1939, vol. 10, July, pp. 203–209). The authors discuss means of determining fatigue stresses in airship and aeroplane parts and the problems which arise in providing adequate safety factors.

A Study of the Thermal Conductivity and the Electrical Resistance of Cast Iron. J. Maréchal and J. Listray. (Revue de Métallurgie, Mémoires, 1939, May, vol. 36, pp. 240–250). The authors describe the apparatus they constructed for the measurement of the thermal conductivity of cast iron up to 150–200° C., and they give exact experimental details. The electrical resistance was measured in the well-known way, using a Thomson bridge. The behaviour of a number of cast irons of different compositions and structure was studied. The tests led to the following results: The thermal conductivity of grey cast iron decreased with rising temperature and with increasing phosphorus content. The thermal conductivity of cast bars 75 mm. in dia. was greater than that of bars 35 mm. in dia. A copper content, in some of the bars, had no marked effect. The thermal conductivities of bars of white cast iron was much smaller than those of grey cast-iron bars. The electrical conductivities of the cast bars 75 mm. in dia. were smaller than those of the bars 35 mm. in dia.; the electrical conductivities of the latter decreased with increasing phosphorus content, whereas the composition of the former had no distinct influence. The electrical conductivities of white cast-iron bars were distinctly greater than those of the grey cast-iron bars. The results indicate that the Wiedemann and Franz law cannot be applied to cast iron.

The Melting Points of Metals. B. N. Svetchnikoff. (Metallurg, 1939, No. 3, pp. 28–36). (In Russian). This is a treatise on the relation between the melting points and coefficients of expansion of

metals, in which the author analyses the graphs showing this relation in respect of pure metals of the cubic system. He is of the opinion that the expansion takes place in two stages. In the first the coefficient of expansion changes with temperature more rapidly than in the second. The transition point between the two stages is marked by a distinct inflection, and the temperature at this point may be called the critical temperature. The coefficient of expansion during the first stage from the absolute zero to the critical temperature is different for different metals. For the metals investigated by the author this varies between 0·0005 for platinum and 0·0057 for aluminium, and for elements of one group it decreases as the atomic number increases. In the second stage, that between the critical temperature and the melting point, the coefficient of expansion is approximately constant at 0·065, the case of silver being an exception. The author obtained the data for these curves by calculation from the lattice parameters of the metals at room temperature and from the coefficients of expansion. He also examines the relation between the melting points of metals, their places in the periodic table of elements and the crystal lattices. For the groups VA. to VIIIA. the transition to the adjacent elements in the direction of increasing atomic numbers is accompanied by a considerable rise of temperature. In the groups IVA., VIIIC. and IIIC. a temperature change of the same nature takes place but the increase is less. In the elements of the groups VC. and IIC. the transition to the adjacent elements in the direction of increasing atomic numbers is accompanied by a lowering of the melting points. These conclusions were obtained by plotting two series of curves; in the first the melting points are plotted against the atomic numbers, and in the second the products of the lattice parameters and the coefficients of expansion are plotted against the atomic numbers.

Embrittlement of Creep-Resisting Steels at High Temperatures. (Metallurgist, 1939, vol. 12, June, pp. 46–48). An abridged English translation is given of R. Scherer and H. Kiessler's paper on the embrittlement of heat-resisting steels at high temperatures which appeared in Archiv für das Eisenhüttenwesen, 1939, vol. 12, Feb., pp. 381–385 (*see* Journ. I. and S.I., 1939, No. I., p. 299 A), and the conclusions of these authors are discussed and compared with those of other investigators.

Creep of Metals at High Temperature in Bending. E. A. Davis. (Transactions of the American Society of Mechanical Engineers, 1938, vol. 60, pp. A-29–A-31). The author develops a theory for plastic bending and obtains equations for calculating the creep resulting from bending. He also describes some tension and bend tests conducted at 1500° and 1652° F. on specimens of a chromium-nickel steel the results of which supported his theory.

Effect of Temperature Variation on the Creep Strength of Steels. E. L. Robinson. (Transactions of the American Society of Mechanical Engineers, 1938, vol. 60, pp. 253–259). The author

explains, with examples, the application of some formulæ for calculating the effect of temperature fluctuations on the creep rate of steels at elevated temperatures.

Is There a True Creep Limit? U. Dehlinger. (Zeitschrift für Metallkunde, 1939, vol. 31, June, pp. 187–191). The author defines the creep limit of materials as the maximum load which does not cause continuous creeping, but a certain amount of plastic or elastic deformation only. The true creep limit is defined as the constant creep limit still observed after a very long duration. The author develops an equation which leads to an understanding of the different creep properties of amorphous, single- and poly-crystalline substances. He shows that the value of the creep limit for single crystals is zero and that there is no true creep limit for amorphous substances. There is a true creep limit, however, for polycrystalline materials, which is, at least for coarse-grained materials, identical with the fatigue limit.

Steels and Their Utilisation for High Steam Pressures and Temperatures. R. W. Bailey. (Transactions of the Institute of Marine Engineers, 1938, vol. 50, pp. 93–104). The author shows that marine engineering practice can afford to await the results of land development and experience in the selection of suitable boiler material and the choice of working conditions before making its own advance in the same direction. He reviews the position and capabilities of carbon steels and suggests that they may be sufficient to meet most of the requirements of immediate development. He discusses next the effect of temperature in changing the structure and behaviour of carbon steels during service, and submits data showing the increased creep resistance obtained by adding 0·5% and 1–2% of molybdenum to steel. He points out the difficulty of suppressing the intercrystalline cracking under creep of high-creep-resistant steels and shows that the use of welded constructions of this class of steel in boilers where the operating temperature is such that creep considerations dominate design, obviously requires special safeguards to ensure reliability. He concludes his paper with considerations affecting the design of high-pressure joints, bolts and rotating discs to meet creep conditions.

The Scaling of Cast Iron and the Adhesion of the Layers of Scale Formed. E. Piwowarsky and W. Patterson. (Giesserei, 1939, vol. 26, July 28, pp. 381–385). After a review of the theories on the formation of scale on pure metals and alloys, the author describes his experiments showing the comparatively small formation of scale on cast iron, in particular on cast iron rich in phosphorus (0·4–0·8%), and the good adhesion of the scale. Between 650° and 900° C. scale is developed more slowly than on steels; above 850° C. the rates of scale formation become approximately the same. The adhesion of the scale layer is very much greater on cast iron than on steel, in particular between 750° and 900° C.

The Notched-Bar Sensitivity of Alloy Steels at Temperatures between + 20° C. and — 253° C. (Boiling Point of Hydrogen). A. Pomp, A. Krisch and G. Haupt. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 15, pp. 219–230). The authors investigate the notched-bar sensitivity of steels at low temperatures. Sixty-two different alloy steels were tested and those steels with an impact strength exceeding 3 m.kg. per sq. cm. at — 183° C., as well as copper and lead, were tested in liquid hydrogen. The results showed that a number of nickel, chromium-nickel- and chromium-manganese steels—especially those with an austenitic structure—as well as the metals nickel, copper and lead are still capable of considerable plastic deformation at temperatures as low as — 253° C. All the low-alloy martensitic steels showed a falling-off in impact strength down to — 183° C. There were, however, a number of chromium-molybdenum steels with and without small additions of nickel which had an impact strength of 5 m.kg. per sq. cm. at the temperature of liquid air. It was also observed that steels which had been tempered to a high strength had, as a rule, a low impact strength at low temperatures. Soft iron became exceedingly brittle at low temperatures.

Hardness and Tensile Tests on Alloy Steels at Low Temperatures. A. Pomp, A. Krisch and G. Haupt. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 15, pp. 231–241). The authors carried out a number of hardness and tensile tests on specimens of chromium-molybdenum and nickel steels at low temperatures to establish whether the relationship which exists at room temperature, namely, Brinell hardness = tensile strength $\times$ c, where c is a constant between 0·34 and 0·36, also applies at — 183° C. In general the results showed that the hardness increased as the temperature decreased with all of the sixty-two alloy steels tested, but the increase in hardness of those alloys of high hardness at room temperature was less than that of the softer alloys, and the amount of increase in hardness was also dependent on the chemical composition. They also found that in most of the steels tested the ratio of the Brinell hardness to the tensile strength was about the same at — 183° C. as at room temperature.

Alterations in the Mechanical Properties of Commercial Metals at Low Temperatures. A. Krisch. (Zeitschrift des Vereines deutscher Ingenieure, 1939, vol. 83, Aug. 5, pp. 893–898). The author discusses the influence of low temperatures on the tensile and fatigue strength and on the deformability of various steels in order to establish their suitability as material for low-temperature apparatus. He reproduces numerous curves showing the increase in tensile strength, of different steels, with falling temperatures, down to about — 200° C. For the fatigue strength only data down to temperatures of about — 40° C. have so far been published. They seem to indicate that the influence of low temperatures on the fatigue strength corresponds to that on the tensile strength. The author gives a

great number of results, partly obtained by himself, of notched-bar impact tests at low temperatures (down to — 250° C.) showing the decrease in deformability with falling temperature. This decrease is comparatively small for the majority of the austenitic steels studied, however. The author comes to the conclusion that nickel-free steels give at least as favourable results as nickel steels, a fact which is of economic importance to Germany. He suggests, in particular, the use of austenitic chromium-manganese steels for low-temperature apparatus.

First Report of the Research Committee on High-Duty Cast Irons for General Engineering Purposes. J. G. Pearce. (Proceedings of the Institution of Mechanical Engineers, 1938, vol. 140, pp. 163–238). The developments of the past fifteen years have made available to the engineer a much wider range of cast irons. With the object of making known to the engineer the nature of this range and the properties likely to be of service to him in deciding where a particular iron can be used in design, the Council of the Institution of Mechanical Engineers appointed a research committee " to make a systematic and co-ordinated exploration of the properties and performance of high-duty cast irons, with special reference to their development and use for general engineering purposes." The first report of this committee is now presented.

The report is presented in three parts. In Part I. the development of high-duty cast irons during the past fifteen years are reviewed and relate to the material traditionally used. This is illustrated by results given in Part II., derived from materials actually supplied by manufacturers and designed to show the present state of the art. When complete, these records will form the basis on which a major portion of the Committee's programme will rest. The remaining portion of the programme consists of the preparation of materials covering the whole range of cast irons and the determination of their mechanical properties. The first results of this are given in Part III., and it is intended, when the range is completed, to select materials which show sufficient promise for submission to a complete range of mechanical tests. In the meantime, it is hoped that discussion will assist the Committee in its future work.

Some Engineering Aspects of Cast Iron. C. H. Morken. (Mechanical Engineering, 1939, vol. 61, June, pp. 455–459). The author reviews the characteristics of the structure of cast iron, the relation of the structure to its physical properties, the effect of alloying elements and of heat treatment, and finally the significance of the tests prescribed in the specifications of the American Society for Testing Materials.

Alloy Irons in Engineering and Commercial Usage. R. Lowe. (Journal of the Junior Institution of Engineers, 1939, vol. 49, July, pp. 437–451). In this discussion of the properties and applications of alloy cast irons the author surveys the base material and the reasons for making additions of specific elements either alone or in

combination with other elements. In an appendix a number of tables showing the analyses and properties of a large number of alloy cast irons for specific applications are presented.

The Influence of Some Special Additions on Certain Properties of Cast Iron. P. G. Bastien and L. Guillet. (Revue de Métallurgie, Mémoires, 1939, vol. 36, Apr., pp. 149–164; May, pp. 222–239; June, pp. 271–287). This is a French translation of the authors' paper published in the Iron and Steel Institute, Carnegie Scholarship Memoirs, 1938, vol. 27, pp. 77–143. (*See* Journ I. and S.I., 1939, No. I., p. 180 A).

The Importance of Alloy Additions in Special Steels. J. Wagner. (Revue Universelle des Mines, 1939, vol. 15, June, pp. 305–316). The author discusses, mainly from the physico-chemical point of view, the properties of alloy steels, and he considers, in particular, the influence of various alloy additions on the iron-carbon diagram. He divides the alloy additions into four groups, *viz.*, (1) elements which form austenitic steels by depressing the Ar_3 point and simultaneously extend the γ-phase; (2) elements which raise the Ar_3 point; (3) elements which, like carbon, depress the Ar_3 point and extend the γ-phase but form heterogeneous equilibrium systems at low temperatures; (4) elements which also form complete systems at low temperatures which, however, reduce the area of the γ-phase at higher temperatures. The effects of the following alloy additions are discussed in some detail: Manganese, nickel, chromium, tungsten, molybdenum, vanadium, cobalt, silicon, aluminium, copper, and nickel-chromium, chromium-manganese, and various other combinations of the above elements, in particular those applied for the production of high-speed steels and of permanent magnets.

The Effect of Low Copper Contents on the Strength Properties of Low-Alloy Structural Steels, Especially Steel St 52. E. Houdremont, H. Bennek and H. Neumeister. (Technische Mitteilungen Krupp, Forschungsberichte, 1939, vol. 2, Aug., No. 9, pp. 99–114). The authors first review the literature on the effects of additions of up to 0·9% of copper on the corrosion- and wear-resisting properties of structural steel, pointing out the general conclusion that high-strength steels which, because of their alloy content, are in the critical-cooling-velocity range when cooled in air can have their elastic limit and tensile strength increased by 1–3 kg. per sq. mm. They next report on their own investigations using manganese and manganese-chromium steels, as a result of which they found that additions of 0·15% and 0·45% of copper to cast manganese steel of the St 52 type increased the elastic limit by 1–4 kg. per sq. mm. and the tensile strength by 2 kg. per sq. mm. max. The effect of adding copper to manganese-chromium steels was not so marked, but, generally speaking, the addition of up to 0·5% of copper was beneficial. The authors also studied the effect of copper additions on the welding properties and find that copper increased the hardenability rather than the absolute hardness of steel, and there was, therefore,

no danger of the formation of brittle zones adjacent to welds in copper-bearing steel.

Silver Added to 18-8. (Steel, 1939, vol. 104, June 12, pp. 58–62). Some particulars are given respecting a recent United States patent for stainless steels containing small additions of silver. The most important claim made is that the addition of silver effectively prevents the pitting-corrosion of 18/8 chromium-nickel steel in sea-water. Other claims include improved machinability, higher thermal conductivity and ability to obtain a better polished surface. Six different analyses are given; in the three of these which are recommended for resistance to pitting-corrosion there is from 0·25 to 0·42% of silver present; for free-machining 0·15%, for good polishing 0·50% and for high thermal conductivity 0·14% of silver are recommended.

The Limits of the Strength Properties of Chromium-Molybdenum Structural Steels after Hardening or Tempering. H. Voss and F. Krämer. (Stahl und Eisen, 1939, vol. 59, Aug. 10, pp. 913–920). The authors investigated the changes in the strength properties of chromium-molybdenum steels in relation to the dimensions of the specimen and the contents of carbon, manganese and chromium. They determined and compared the tensile strengths of quenched specimens down to 5 mm. in dia. and present a table of the results of tests of 104 melts of steel containing carbon 0·14–0·50%, chromium 1·05–3·21% and molybdenum 0·18–0·39%.

Chromium Steel Castings. K. Roesch. (Giesserei, 1939, vol. 26, July 14, pp. 357–360). In this general description of the properties of chromium-steel castings, the author shows what a wide range of properties can be imparted to the steel by the addition of different percentages of chromium. The addition of 1–2% increases the strength sufficiently to allow a saving of weight, and the susceptibility to heat treatment is improved by the addition of molybdenum. With 6% and upwards of chromium the steel becomes heat-resisting, and with 12–16% and a low carbon content it is corrosion-resistant. In cases where high strength combined with both corrosion and heat resistance are required, cast steel containing 12–16% of chromium is better than copper-bearing steel.

Phosphorus-Bearing Steel for Thin Tinplate. G. L'vov and S. Broyt. (Stal, 1938, No. 12, pp. 12–17). (In Russian). Phosphorus was chosen as an element which, while reducing the sticking tendency of sheets during hot-rolling, would not at the same time affect the structure of the ingot of the rimming steel which has to be used and would not lower the mechanical properties of the sheet. Preliminary experiments, as well as the subsequent one year's production experience summarised in this article, show that phosphorus-bearing steel containing carbon 0·09–0·12%, manganese 0·30–0·40%, phosphorus 0·09–0·12%, sulphur up to 0·05% and traces of silicon is quite suitable for the production of white sheet and for this purpose is superior in many respects to silicon-bearing steel. Sound

ingots and a reduction in defects (such as blisters, pickling blisters, non-metallic inclusions and sticking), together with satisfactory mechanical properties, were obtained. Some mention is made of special features of the open-hearth process for the production of phosphorus-bearing steels.

Effect of the Melting Process on the Physical Properties of Carbon Tool Steel. V. M. Zamoruev and L. S. Lavrent'ev. (Metallurg, 1939, No. 1, pp. 41–50). (In Russian). In the present work the authors report on an investigation of the effect of agents having a deoxidising effect, such as carbon, carbide slag, silicon and aluminium, and of the process of oxidation of the bath by the addition of iron ore on the formation of austenite. The experimental heats were made in a 3-ton arc furnace. The oxidising period was the same for all heats, but the deoxidising period was varied by: (1) Refining, using a carbide slag and one of the following process of deoxidation: (*a*) Carbide slag $\longrightarrow$ ferro-silicon $\longrightarrow$ aluminium, (*b*) carbide slag $\longrightarrow$ aluminium $\longrightarrow$ ferro-silicon, and (*c*) carbide slag $\longrightarrow$ ferro-silicon. (2) Refining under a white slag and deoxidation with aluminium $\longrightarrow$ ferro-silicon $\longrightarrow$ aluminium. Samples taken at various stages during the heat were examined for hardenability and McQuaid-Ehn grain size, and analysed to determine their ferrous oxide, nitrogen and hydrogen contents. The authors conclude that changes of the properties of the metal take place throughout the heat. Samples taken immediately after melting showed a fine grain owing to the presence of scattered oxide inclusions. These, however, are subsequently coagulated and removed by the ferrous oxide during the boil, this being accompanied by a coarsening of the grain. This coarse grained steel will only harden to a shallow depth, in spite of the high carbon content (0·6–0·9%) owing to the very low contents of silicon, manganese and other alloying elements on the one hand and the appreciable content (0·05%) of ferrous oxide on the other. The effect produced by additions of aluminium depends to some extent on the slag used and also differs from the effect of deoxidising with ferro-silicon. While the addition of aluminium markedly refines the grain size and also reduces the hardenability, ferro-silicon refines the grain only slightly but considerably improves the hardenability. Determinations of the hydrogen content in one of the heats confirmed that this was raised by the addition of ferro-silicon.

Metals in Chemical Engineering. V. Harbord. (Proceedings of the Chemical Engineering Group of the Society of Chemical Industry, 1938, vol. 20, pp. 31–36). The author discusses the particular properties demanded of metals or alloys in use in chemical engineering under the following headings: (1) The ability to withstand chemical attack from the materials used in the process under more or less normal conditions of temperature and pressure; and (2) the ability to operate at elevated temperatures and pressures while being in many cases exposed to serious corrosive con-

ditions. He also shows by reference to practical examples how the close co-operation of chemical engineers and metallurgists has contributed to the progress made.

Ferrous Metals in Chemical Industry. F. Moss and P. L. Martyn. (Society of Chemical Industry of Victoria, 1938, vol. 38, Oct.–Nov., pp. 110–122). In the first part of the paper the alloy additions which make cast iron suitable for use at high temperatures are reviewed. The second part deals with the corrosion of a number of ferrous alloys, with particular regard to their use in chemical industry; their losses in weight under the influence of various chemical agents are tabulated in order to show how, by suitable alloying, corrosion can be prevented. In the third part of the paper a very brief review is given of the fabrication of chemical plant, using cast iron.

Metals and Alloys Used in Making Rubber Tires. E. F. Cone. (Metals and Alloys, 1939, vol. 10, July, pp. 198–202). The author describes the moulds used in the manufacture of motor tyres, giving particulars of the composition of the ferrous and non-ferrous alloys of which they are made.

Concrete Reinforced with Steel Wire. A. Kleinlogel. (Stahl und Eisen, 1939, vol. 59, Aug. 3, pp. 896–898). The author describes a new method of making reinforced concrete beams the use of which results in a great saving in wood and steel required in building construction. The process of manufacture has been developed by E. Hoyer. In previous processes the reinforcing rods were 10 mm. in dia., and were held at a tension of 600–800 kg. per sq. cm. while the concrete set. Hoyer, however, instead of using one 10 mm.-dia. rod, uses fifty wires 1·5 mm. in dia. of a steel containing carbon 0·6–1·0% and manganese 0·3–0·5% subjected to a tensile stress of 12,000–18,000 kg. per sq. cm. As the surface area of the fifty wires is so much greater than that of one rod of larger diameter, the adhesion of the concrete is correspondingly greater, and it is therefore unnecessary to have the ends of the wires bent into hooks. Hoyer has developed equipment for making wire-reinforced concrete beams in lengths of 100 m. which can be cut to any desired length. Numerous tests have demonstrated that the mechanical properties of these beams are quite satisfactory.

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 228 A–235 A)

Metallography in the Wire Industry. C. G. Johnson. (Wire and Wire Products, 1939, vol. 14, June, pp. 306–309, 348). In this paper, which is primarily intended for those wire makers not very familiar with the use of the microscope, the author describes and illustrates the constituents of steel, including ferrite, cementite, pearlite, martensite, manganese sulphide and oxides. He also explains how the effects of cold-work, annealing and decarburisation on steel wire can be studied with the microscope.

The Determination by X-Rays of Strains Caused by Dynamic Stresses. R. Glocker, G. Kemmnitz and A. Schaal. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, Aug., pp. 89–92). The authors describe some recent refinements in X-ray equipment which permit of the more accurate determination of the elastic strains in steel produced by fatigue stresses. These include the use of a synchronously rotating shutter placed between the material and the film.

The Applications and Limitations of the Magnaflux Testing Method in Shipbuilding and Marine Engineering. E. Hemmerling. (Stahl und Eisen, 1939, vol. 59, Aug. 17, pp. 937–942). Examples are enumerated of defects which can be detected in marine engineering practice by application of the magnaflux method, which allows the detection of surface cracks of all kinds in cast and forged material. It is not suitable, however, for the detection of globular inclusions, cavities or cracks which are in the interior of the material. The two main advantages of the magnaflux method are simplicity and low cost.

Processes for the Production of Metallic Single Crystals. H. Schoeneck and H. Uerleger. (Metallwirtschaft, 1939, vol. 18, June 30, pp. 576–584). After a general discussion on the properties of single crystals, with particular reference to the determination of their orientation, the authors review the methods of producing them. These methods are classified in three groups, *viz.*, the production of single crystals from the solid, liquid and gaseous states, and for each group numerous examples are cited. The paper includes 80 references to the literature.

The Problem of the Primary Crystallisation of Steel : The Undercooling Capacity and the Formation of Nuclei in the Liquid State. P. Bardenheuer and R. Bleckmann. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 13, pp. 201–212). The authors studied the undercooling of low-carbon steels by

plotting time-temperature curves from the results of tests in a Tammann furnace. They found that with a cooling rate of about 40° C. per min., and by maintaining certain conditions, undercooling to the extent of 250° C. could be obtained, and in such cases the rate of crystallisation was very high. When a melt was not undercooled to this extent a certain time elapsed before spontaneous crystallisation commenced; with undercooling by less than 150° C. this time lag was quite considerable. These experiments showed that at ordinary cooling rates a melt of low-carbon steel is in a very unstable state before spontaneous crystallisation begins; during this period external causes, such as the roughness of the inside of the crucible, may quite easily cause crystallisation. The authors also investigated steels with up to 1·38% of carbon, and found that, as the carbon increased, the extent of undercooling obtainable decreased, from which fact they conclude that when casting steel in chills the tendency to spontaneous crystallisation has no effect upon the solidification at the centre of the ingot. The authors also tested the effect of the temperature of the melt upon the degree of undercooling, and found that, after superheating the steel to about 20° C. above the liquidus line, it was possible to obtain maximum undercooling and this maximum was unaffected either by extending the time for which the superheating was maintained, or by raising the superheating temperature. Finally, the authors examined the effect of the presence of other elements on the undercooling of steel, and established that additions of aluminium, beryllium, boron, calcium-aluminium (20%/80%), calcium-silicon-aluminium (21·6%/42·15%/15·6%), titanium, vanadium or zirconium completely prevented undercooling; on the other hand, the more common additions, such as nitrogen, manganese, silicon and calcium-silicon, chromium, cobalt, molybdenum, nickel, niobium + tantalum, phosphorus, sulphur, tungsten, carbon together with silicon, chromium, tungsten and chromium + tungsten, do not prevent undercooling. Hydrogen and iron oxide considerably reduce the degree of undercooling obtainable.

The Crystallisation of Graphite during the Solidification of Cast Iron. H. Hanemann and A. Schrader. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, Aug., pp. 85–86). The study of microsections indicated the existence of a stable and a metastable eutectic in cast iron as was to be expected according to the double phase diagram of Ruer and Goerens (Stahl und Eisen, 1918, vol. 38, May 19, p. 423). This modification of the iron-carbon diagram covers all structural changes so far observed in cast iron.

Determination of the Grain Size in Structural and Tool Steels by the Oxidation Method. N. S. Vaynshteyn and E. V. Dombrovskaya. (Zavodskaya Laboratoriya, 1939, No. 2, pp. 228–229). (In Russian). The authors determined the grain size of structural and tool steels by oxidising the boundaries of the austenite grains by heating polished specimens in an oxidising atmosphere and quenching in water or oil,

and they compare these with the grain size obtained by a two hours' cementation treatment at 920° C., followed by cooling in the furnace to 700° C., holding for 10–15 min. and quenching in water. They find that the results obtained by the oxidation method are influenced by the temperature at which oxidation took place.

Carbon Steels with Austenite Grains of Controlled Size. I. Fetchenko-Tchopivski. (Revue de Métallurgie, Mémoires, 1939, vol. 36, May, pp. 205–211). The author applies the expression "controlled grain size" to steel having the grain size of austenite. Such steel can be obtained by a special process which is based on the addition of, preferably, aluminium to steel immediately before or, in some cases, during the casting process. No details of the method of making this addition are given, but the author discusses at some length the influence of the grain size on the properties of steel, and the effect of mechanical working and heat treatment on the grain growth.

The Transformation of Residual Austenite in High-Alloy Steels at Temperatures Below 0° C. A. P. Gulyaev. (Metallurg, 1939, No. 3, pp. 64–71). (In Russian). Earlier work is summarised. The present investigation was carried out on high-speed steel (carbon 0·74%, tungsten 18·2%, chromium 4·01%, vanadium 0·58%), high-chromium steel (carbon 1·85%, chromium 10·38%) and silchrome (carbon 0·44%, chromium 11·0%, silicon 3·85%). Temperatures down to — 180° C. were applied in a special apparatus in which the amount of austenite present in the specimens was measured by the magnetic induction method. In the case of steels quenched from comparatively low temperatures, although some residual austenite was present, they did not change into martensite on cooling down to liquid-oxygen temperatures. As the quenching temperature was raised, the temperatures of both the upper and lower martensite points were lowered, the latter, which was determined in the present investigation, falling considerably below 0° C. The martensite transformation exhibited low hysteresis. At the end of the transformation a certain amount of stable residual austenite was left unchanged.

Influence of the Rate of Cooling on the Transformations and Properties of Chromium Steels. A. Rose and W. Fischer. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 8, pp. 133–145). The authors commence with an examination of the behaviour on cooling of steel containing 0·30–3·7% of chromium and 0·25–1·7% of carbon and reproduce the undercooling curves for twenty-two steels in this range of composition. When more than 0·3% of chromium is present there are three stages of undercooling: The pearlite stage, the intermediate stage and the martensite stage; each stage is characterised by its structure and hardenability, which the authors discuss in detail. The critical cooling rates are lowered to a marked degree by small additions of chromium. With 1% of chromium and eutectoid

carbon present the critical cooling rate is 30° C. per sec., which is one-seventh of the critical cooling rate of unalloyed steel. The intermediate stage of transformation occurs only within a limited range of chromium and carbon contents. The authors consider next the nature of the intermediate stage. The pearlite and intermediate transformation stages have, as revealed by isothermal magnetic measurements, two distinct maximum rates of austenite precipitation, one at 680° C. and the other at 480° C. Determinations of the Curie point of specimens, some of which were transformed in the pearlite stage and others in the intermediate stage, revealed that in the latter specimens the carbide which was formed was much lower in chromium than was the carbide in the former specimens. Carbides low in chromium were, however, also formed when quenched martensitic steels were held for some time (20 min.) at the intermediate or pearlite stage temperature and tempered. From a microscopic examination of the structure it is revealed that the transformations take place very rapidly at definite points with the formation of needle-like crystals. Counter to this, there is also a process of diffusion which tends to make the precipitated carbides coalesce, but this tendency decreases as the precipitation temperature decreases. In conclusion the authors discuss the mechanical properties of the steels transformed in the intermediate stage, and find that those low in carbon (0·30–0·35%) have better properties than those which have been annealed, in fact their properties approach those of tempered steel.

The Iron-Cobalt-Tantalum System. W. Köster and G. Becker. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, Aug., pp. 93–94). The iron-cobalt-tantalum system has been studied under the postulation of a solid-solution series of the two compounds Fe_2Ta and Co_5Ta_2, as only one compound phase has been observed. The phase diagram has so far been determined, although not yet in all detail, for the Fe–Co–Fe_2Ta–Co_5Ta field. The mechanical and magnetic hardening of the alloys have been studied. There are certain similarities between the system under investigation and the iron-cobalt-molybdenum and the iron-cobalt-tungsten systems.

The Iron-Nickel-Tin Constitutional Diagram. P. Schafmeister and R. Ergang. (Technische Mitteilungen Krupp, Forschungsberichte, 1939, vol. 2, Aug., No. 11, pp. 125–138: Archiv für das Eisenhüttenwesen, 1939, vol. 13, Aug., pp. 95–103). The authors study the Fe–Ni–Ni_3Sn_2–Fe_2Sn–Fe portion of the iron-nickel-tin constitutional diagram by thermal and microscopic examinations. The compound Ni_3Sn, which has a congruent melting point, and the compound Fe_2Sn, which has an incongruent melting point, form an uninterrupted series of solid solutions. Two four-phase transformations and four primary planes of separation (α, γ, ε and β) occur in the diagram. The authors also examine the increase in hardness due to the decreased solubility of tin in ferrite and austenite, and measure the hardness, coercive force and remanence of the alloys.

The Oxygen-Titanium Equilibrium in Iron Melts. H. Wentrup and G. Hieber. (Technische Mitteilungen Krupp, Forschungsberichte, 1939, vol. 2, Aug., No. 10, pp. 115–123: Archiv für das Eisenhüttenwesen, 1939, vol. 13, Aug., pp. 69–72). It is known that titanium has a strong affinity for oxygen in molten steel and therefore tends to form oxide inclusions. With the object of obtaining data on the strength of these reactions, the authors investigated the oxygen-titanium equilibrium in a series of melts in which titanium was added to Armco iron. They found that titanium is a much stronger deoxidising agent than silicon, but is not so strong as aluminium. By means of microscopic examinations they constructed the equilibrium diagram for the system Fe–FeO–$FeO.TiO_2$–Ti_2O_3–Fe_2Ti.

CORROSION OF IRON AND STEEL

(Continued from pp. 236 A–238 A)

The Study of Corrosion in England. N. Goldowski. (Métaux et Corrosion, 1939, vol. 14, No. 167, pp. 103–107). This is a concise report on the activities of the Corrosion Committee of the Iron and Steel Institute dealing with the researches on atmospheric and marine corrosion.

The Development of the Studies of Corrosion at Cambridge University. U. R. Evans. (Korrosion und Metallschutz, 1939, vol. 15, May, pp. 141–144). The author reviews the work carried out at Cambridge University on (1) the oxidation of dry metals; (2) the electrochemistry of the corrosion of wet metals; and (3) the formation of protective layers and the prevention of corrosion.

Metals and Alloys Resistant to Acid Agents at Raised Temperature. A. M. Krawczynski. ((Chimie et Industrie, 1939, vol. 41, June, pp. 1051–1060). The author reviews the recent developments in the production of alloys steels suitable for resisting the attack of sulphuric acid and acetic acid at raised temperatures.

The Study of Cathodic Reactions in Metallic Corrosion. T. P. Hoar. (Electrochemical Society, Sept. 1939, Preprint No. 18). The importance of the study of cathodic reactions under conditions similar to those of natural corrosion is pointed out, and the danger is stressed of extrapolating results obtained at higher current densities to those occurring in corroding systems. The mechanisms of the hydrogen-evolution and oxygen-dissolution cathodic reactions are discussed, especially in relation to oxide and so-called hydride films and, in the case of iron, to the diffusion of cathodic hydrogen through the metal. The influences of inhibitors and of depolarising accelerators are briefly considered.

The Nature of the Cathode in the Rusting of Iron. S. Brennert. (Electrochemical Society, Sept. 1939, Preprint No. 8). The author studied the corrosion of iron in a flowing aerated sodium-chloride solution using in one case Armco iron and steel and in another Armco iron and cast iron electrodes. In acid solution, as has been known for a long time, the impurities form the cathodic areas, and cast iron and steel, therefore, become cathodic in relation to Armco iron, which is relatively pure. In neutral solutions, however, the importance of the impurities as cathodic areas is negligible, and here the Armco iron acquires a decided cathodic potential. This is due to the formation, on the Armco iron, of an oxide film which is more homogeneous, and consequently is not so readily attacked as that on cast iron and steel.

The Classification of Anodic and Cathodic Inhibitors. E. Chyżewski and U. R. Evans. (Electrochemical Society, Sept. 1939, Preprint No. 10). In order to be able to distinguish between cathodic and anodic corrosion inhibitors, the authors used a divided cell for their experiments. The cell contained iron and copper electrodes when testing for anodic inhibitors, and iron and zinc electrodes when testing for cathodic inhibitors. Usually potassium sulphate was used as the electrolyte. A falling-off of the current when the substance under test was introduced into the iron compartment indicated an inhibitor, and an increase of current a stimulator. Sodium hydroxide and carbonate were found to act as both anodic and cathodic inhibitors, zinc sulphate and emulsifying oil as cathodic inhibitors only. In the presence of alkali, chromate inhibits the cathodic reaction, but in the presence of acid there is a marked stimulation at the cathode; chromates act as anodic inhibitors in neutral but not in acid solutions. Magnesium sulphate proved to be a cathodic stimulator. Various organic inhibitors were also studied.

The Degree of Chemical Heterogeneity in Ordinary 18/8 Steels Due to Reheating. A. L. De Sy and H. Haemers. (Métaux et Corrosion, 1939, vol. 14, July, No. 167, pp. 97–102). The authors have tried to prove experimentally the theory which suggests that the proneness to intercrystalline corrosion of 18/8 chromium-nickel steel after reheating at 700° C. is due to the formation of the carbide CrC_4 in the grain boundaries; as a consequence the chromium content in the grain boundaries is decreased and the latter become less resistant to chemical attack. The authors exposed reheated 18/8 chromium-nickel steel to the attack of a solution containing 10% of sulphuric acid and 10% of copper sulphate, and they found that the percentage of chromium in the metal dissolved is lower than in the original steel up to the point when the grains themselves are attacked, *i.e.*, when the steel begins to crumble.

The Mechanism and the Causes of Intergranular Corrosion. G. Chaudron. (Revue Universelle des Mines, 1939, vol. 15, Aug., pp. 388–392). The author divides the causes of intergranular corrosion into three groups: (1) Characteristic properties of metals liable to intergranular corrosion, *viz.*, internal stresses, heterogeneity due to unsuitable annealing or cold-working, lack of intercrystalline cohesion, coarse grain size. (2) Application and working of the metal, *viz.*, external stresses, welding, brazing, temperature and pressure of application, cold-hardening. (3) Properties of the attacking agent, *viz.*, its composition, impurities and gas development. Suggestions are made for the elimination of each of these points. A general introduction is given into the theories of the mechanism of intergranular corrosion.

The Attack of Hydrogen Sulphide on Steel. G. Ballabio and G. Pastonesi. (Metallurgia Italiana, 1939, vol. 31, July, pp. 431–436). The loss in weight, due to the attack of hydrogen sulphide,

and its dependence on the temperature, the partial pressure of hydrogen-sulphide and the duration of exposure have been determined for a number of steels and alloy steels. The 18/8 chromium-nickel steel proved to be particularly resistant.

The Cathodic Behaviour of Zinc *versus* Iron in Hot Tap-Water. G. Schikorr. (Electrochemical Society, Sept. 1939, Preprint No. 13). Tests on galvanised steel pipe showed that the zinc in the coating behaved as a cathode when submerged in hot tap-water. As a rule, however, this cathodic behaviour of zinc could be definitely established only at temperatures above about 70° C. The experimental results seem to clarify a number of apparently unusual corrosion phenomena observed in practice with galvanised pipe used in hot-water service.

Modern Conceptions of Hot- and Cold-Water Corrosion. L. W. Haase. (Korrosion und Metallschutz, 1939, vol. 15, May, pp. 150–157). The author reviews recent work on the corrosion caused by hot and cold water and stresses in particular the danger of corrosion due to the formation of local cells in iron pipe systems with copper fittings. He briefly describes his own investigations on the influence on corrosion of impurities contained in water and he compares the corrosion-inhibiting effect of different methods of water purification.

The Corrosiveness of Drinking Waters. O. L. Bihet. (Revue Universelle des Mines, 1939, vol. 15, Aug., pp. 393–398). The author reviews modern conceptions on corrosion, mainly that of iron, caused by drinking water, considering separately the corrosion caused by hard and soft waters. The methods employed for rendering water less corrosive are discussed briefly.

The Corrosiveness of Drinking Water. A Method for the Direct Measurement of Corrosion and the Results Obtained. H. Goldstein. (Revue Universelle des Mines, 1939, vol. 15, Aug., pp. 398–409). The author describes simple " corrosimeters " used at the Usines à Tubes de la Meuse for studying the corrosiveness of water and the effect of various methods of purifying it. Each corrosimeter is composed of a 1-litre Erlenmeyer containing a coil of steel wire of given dimensions (10 turnings of 15 mm. dia. at 2 mm. pitch) and composition (carbon $< 0{\cdot}1\%$, manganese about $0{\cdot}4\%$, sulphur and phosphorus $< 0{\cdot}05\%$). The Erlenmeyer is closed by a rubber stopper with two holes, so that it is possible, if desired, to study the effect of running water. The amount of iron dissolved is titrated after certain intervals of time. Numerous curves are reproduced in which the amount of iron dissolved by different kinds of water is plotted against the time. The results show the influence on the corrosive effect of water of its *p*H value and hardness, of various gases, acids and salts dissolved and, in particular, of several methods of purification. The author has also studied certain types of coatings produced on steel coils by some waters; some of these coatings are protective.

The Corrosion of Iron in Soil and the Influence of the rH Value. G. Guzzoni. (Korrosion und Metallschutz, 1939, vol. 15, May, pp. 144–150). The author uses the symbol rH to express the ratio of oxidising to reducing substances present in soil. He studies the corrosion of a carbon steel (carbon 0·15%, manganese 0·55%, silicon 0·22%, phosphorus 0·042%, sulphur 0·034%, and traces of copper). Using cylindrical test-pieces 100 mm. in length and 10 mm. in dia., he determined their loss of weight after being buried for five months in various kinds of soil. In an oxidising medium (rH > 27) the loss in weight increased considerably with decreasing pH values. In a slightly reducing medium (rH = 18–25) the loss in weight was not quite so much. In a strongly reducing medium (rH = 10–15), there was, as a rule, less corrosion, reaching a minimum at pH 7, and markedly increasing in alkaline solutions.

The Destruction of Material by the Impact of Water under Single and Continuous Blows. M. Vater and W. Sorberger. (Zeitschrift des Vereines deutscher Ingenieure, 1939, vol. 83, June 17, pp. 725–728). The authors report on an investigation of the eroding effect of a stream of water on steel, glass and rubber. The tests were carried out in a special apparatus in which an arm carrying the specimen revolved at high speed so as to cut through a jet of water of constant diameter and velocity. They conclude from the results obtained that the force of the water was concentrated on a very small area and produced effects very similar to those caused by pressing a steel ball into a plate.

BOOK NOTICES

(Continued from pp. 244 A–246 A)

BECKER, R., and W. DÖRING. "*Ferromagnetismus.*" La. 8vo. pp. vii + 440. Illustrated. Berlin, 1939: Verlag von Julius Springer. (Price 39 RM.)

The aim of this book is to provide a theoretical insight into modern conceptions of ferromagnetism as an aid to the future development of new magnetic materials suitable for industrial uses. It is the hope also of its authors that a fuller understanding of ferromagnetism will render the results of the research worker more fruitful, whether it leads ultimately to a refutation or a verification of the conceptions herein advanced. From this it will be clear that its greatest appeal is likely to be made among the ranks of theoretical physicists and of industrial research workers engaged in the commercial development of magnetic materials.

This work, then, represents a correlation and critical discussion of existing information on ferromagnetism, but it has its origin in a series of lectures given by one of its authors at the Technische Hochschule in Berlin during the winter of 1934–35. In these lectures it was shown that many apparently unrelated properties of ferromagnetic materials could be correlated by means of theoretical and experimental researches into questions of strain, magnetostriction and magnetisation, and related phenomena. Since that time, however, our knowledge of these subjects, and the clarification of existing knowledge which the new data and conceptions make possible, have advanced so rapidly as to warrant a thorough review of the whole subject, this new review thus taking the form of the present work. Its publication was, in fact, foreshadowed in a paper given recently by Professor Becker on "Internal Strains and Magnetism" at the recent conference on "Internal Strains in Solids" at Bristol University.

Research work on ferromagnetism may be broadly divided into two classes, namely, that mainly concerned with explanations as to the origin of magnetisation, and that related chiefly to its manifestations and applications. Both types of research are accorded appropriate consideration in this book. Thus, for convenience in developing the discussion, the text is divided into six sections, of which the first two deal briefly but adequately with existing theories of ferromagnetism. These two sections refer also to the latest theoretical researches, and thus include a discussion of recent conceptions of the transformation taking place at the Curie point. The applications of quantum considerations to the study of ferromagnetic materials are also indicated, the primary object of these two preliminary sections being that of providing a brief outline and introduction to problems brought forward for later discussion. It is, however, in these two sections that metallurgists are likely to find chief interest, and they should thus prove profitable reading, even though from the physicist's point of view they may not be altogether essential to a general understanding of the later sections which are essentially mathematical in treatment.

The three sections which follow represent the major concern of its authors, for they deal more particularly with spontaneous magnetisation, and are thus the most important and the most detailed. The

subject is treated theoretically on the basis of magnetisation curves, and a detailed summary of possible interpretations is provided in the course of the discussion. These sections preserve the character of a critical review, but attentive and perhaps also repeated reading would here seem essential in order that the subject may be understood fully. Much of the experimental data forming the basis of these discussions is here published for the first time, but in developing the subject the results of many other researches have of necessity been referred to and accorded appropriate appreciation. The authors remark, however, that some at least of the experimental results which have been previously published have suffered in value from the fact that they represent rather arbitrary observations made with more or less indiscriminately chosen materials.

The final section of the work provides a survey of existing ferromagnetic materials and of their methods of production, without, however, any pretence to complete authority in this aspect of the subject.

Altogether we must regard this as the most authoritative book on ferromagnetism yet published.

W. F. CHUBB.

SCHEER, L. "*What is Steel?*" An Introduction for Everyman to the Science of Steel. Third revised edition. Translated from the German by F. L. Meyenberg. 8vo. pp. xiv + 164. Illustrated. London, 1939: Macdonald & Evans. (Price 6*s*.)

In the preface to this book, which is a translation from the original German by a well-known German expert employed in an English steelworks, the author seeks to justify its necessity on several grounds, not the least important of which is that the technical man is frequently incapable of offering easily assimilated explanations of technical subjects to more commercial men. Another reason advanced is that even experienced salesmen may frequently display a deplorable lack of very elementary knowledge as to what steel is and what it will do. Both statements possess, of course, a certain measure of justification, but it is necessary to realise that the assimilation of technical knowledge demands a certain natural aptitude for information of that type, a property which, not being concerned with their immediate interests, is rarely possessed by men whose outlook is preponderatingly commercial. Nor is such a talent, when possessed, easy to develop in any man after a certain period of non-use. This book does not, however, aim to provide sufficient technical information that the commercial man may dispense with the need to refer special problems to the more technical experts on his staff, but rather aims at providing a background of knowledge as an aid in approaching customers and others who are more technically trained. To achieve such an object a certain measure of simplification must of necessity be introduced, but it is clear that excessive simplification, which, it must be added, the author has been for the most part successful in avoiding, may easily lead to failure to achieve the object in view. An example from this book may in fact be used to illustrate the possibilities of misrepresentation resulting from over-simplifications. In discussing steels of 0·9% carbon content the statement is made that "Such a steel is called eutectoid steel, *i.e.*, well-structured steel." This is a particularly bad example of excessive simplification, for it not only implies that the word "eutectoid" means "well-structured" but it also infers that well-structured steels are always eutectoid. The injury may go even deeper, for the term "well-structured," to which no precise metallurgical definition may be given, is very likely to be

interpreted in the commercial mind as meaning "properly made," an interpretation which would be very far from correct. To the more technical man, however, the author's meaning is clear.

The commercial non-technical man also has some difficulty in grasping the significance of the words "eutectic" and "eutectoid," but the explanations here given may serve to dispel these difficulties. These few comments nevertheless serve to illustrate the dangers of excessive simplification, which may in addition be accompanied by definite inaccuracies. In the present instance only one such inaccuracy has been detected, and this is to be observed in the discussion of the transformations in a 0·5% carbon steel, when the temperatures quoted do not agree with the accompanying diagram. These small errors need correction in any subsequent edition.

In this, the third edition of the book, published originally in 1937, certain revisions and additions have been made. For instance, at the suggestion of the publishers a short survey of production methods has been added. This deals in a general way with the Bessemer and open-hearth processes, with brief references also to the electric furnace and its uses in remelting and refining steel. This section serves as a very effective conclusion to a simple account of steels and their properties, but it is here necessary to warn the prospective reader that the illustrations and text are based upon German practice, which, though similar in principle to corresponding English practice, is at variance with it in certain important respects. This will be clear on scrutinising the specifications of German steels which have been included in appropriate chapters.

W. F. Chubb.

MINERAL RESOURCES

(Continued from p. 183 A)

Canadian Iron Ore. L. D. Huntoon. (Iron Age, 1939, vol. 144, July 20, pp. 52–55). The author presents a brief account with maps of the iron ore and coal reserves in Canada and presents tables of the imports of these raw materials for the last eighteen years. He refers in particular to a recent discovery of hematite ore containing about 58% of iron and very low in sulphur and phosphorus which has been made recently at Steeprock Lake, Ontario, 135 miles west of Port Arthur on Lake Superior.

Hematite Deposits, Steeprock Lake. M. W. Bartley. (Transactions of the Canadian Institute of Mining and Metallurgy, 1939, vol. 42, July, pp. 359–370). Steeprock Lake is near the village of Atikokan on the south line of the Canadian National Railway, 135 miles west of Port Arthur. The author describes the topography of the area and previous geological work on and previous history of the hematite deposits in this locality, gives an account of the structural geology and of development work on the deposits, and deals with the age and origin of the ore and the composition and grade of the material. This hematite appears to be of high grade and pure in comparison with other North American iron ores; the silica, phosphorus and manganese are low, and the sulphur content is below the limit for furnace requirements, while the iron appears to vary between 55 and 65%.

The Iron Ores of Yampi Sound, Western Australia. F. Canavan and A. B. Edwards. (Proceedings of the Australasian Institute of Mining and Metallurgy, 1938, June, No. 110, pp. 59–100). The authors present a comprehensive survey of the iron ore beds of Yampi Sound, which is a small channel in the Buccaneer Archipelago on the northern coast of Western Australia. The deposits are of the Lake Superior type and also resemble the iron ore deposits in the Middlebank Ranges of South Australia.

Heavy Industries of the German Reich. (Iron and Coal Trades Review, 1939, vol. 139, Sept. 22, pp. 411–412). In the first of this series of articles a review is presented of the position with regard to the requirements and supply of iron ore for Germany. The imports of ore are analysed by countries and the present position is compared with that of 1914–18. It is stated that, assuming that Germany will continue to obtain ore from the neutral countries, there will still be a deficit of about 9,000,000 tons per annum owing to the cessation of imports from France, Spain, the French possessions and Newfoundland.

The Development and Present Position of the Preparation and Smelting of the South Baden Dogger Ores at the Saar Works. A. Graff. (Stahl und Eisen, 1939, vol. 59, Aug. 24, pp. 961–967). The author gives an account of the development of the production and preparation of the iron ores in the Saar district, and describes the Lurgi process of ore preparation by reduction-roasting with subsequent dry magnetic separation. He also discusses the economic aspect of the production of pig iron from these ores.

The Usable Stone and Ores of the Saar and Their Exploitation. A. Graupner. (Zeitschrift für praktische Geologie, 1939, vol. 47, May, pp. 85–97; June, pp. 106–118; July, pp. 121–132). In this comprehensive review of the occurrence and exploitation of the clays, stone and minerals of the Saar district the principal items of interest to the iron and steel industry are the data respecting limestone and clays for making refractory bricks.

The Ore Deposits of Slovakia. K. Rösner. (Berg- und Hüttenmännische Monatshefte, 1939, vol. 87, Aug., pp. 158–164). The mineral wealth of Slovakia includes ores of iron, manganese, copper, mercury, antimony, cobalt and precious metals. The author discusses past and present-day production of these ores and the possibilities of future development. The iron-ore and pig-iron outputs have varied widely down the years, but in 1938 the iron-ore production amounted to 990,285 tons and 46,593 tons of pig iron were made. In recent years the iron in the ore has averaged about 34–35% and the manganese 2%, which figures after dressing, roasting, &c., were raised to 48–52% and 2·5–3%, respectively. The manganese deposit in Hügelland is a manganiferous schist; the metal contents in the years 1925–36 varied from 17% of manganese with 3% of iron to 18·71% of manganese with 2·88% of iron, the phosphorus content being low. Other deposits of manganese are of low grade, but an occurrence in West Slovakia runs to 11% of manganese with about 40% of silica. Outputs of manganese ore in recent years are not quoted, but for 1917 the figure was 72,437 tons.

The Geology and World Resources of Chrome Ores. J. Harroy. (Revue Universelle des Mines, 1939, vol. 15, June, pp. 290–304). After enumerating the chromium-bearing ores, the author studies the forms in which they occur and their relative richness. He also presents data concerning the distribution of the ores throughout the world, the annual production by countries and the estimated quantities available.

REFRACTORY MATERIALS

(Continued from pp. 251 A– 253 A)

The Relative Safe Rates of Drying of Some Different Clay Sizes and Shapes. H. H. Macey. (Transactions of the British Ceramic Society, 1939, vol. 38, Aug., pp. 464–468). The author describes an investigation of the safe rates of drying of a fireclay mix containing about 30% of grog and having an initial moisture content of 20%. The sizes investigated were (1) a brick $9\frac{5}{8}$ in. × 5 in. × $2\frac{3}{4}$ in., standing on edge; (2) a brick of the same size lying flat; (3) a slab 18 in. sq. × 1 in. thick; (4) a 6-in. cube; (5) a 9-in. cube; and (6) a 12-in. cube. From the results obtained the following maximum safe rates of drying (in grammes per hour per square foot) were deduced: (1) 60, (2) 57, (3) 50, (4) 55, (5) 19·5, and (6) 9. The author also examines the relation between this safe rate and the size in respect of fireclay cubes and finds that the reciprocal of the fastest safe rate of drying is proportional to the length of the side of the cube raised to the power 2·6.

Some Observations on the Safe Drying of Large Fireclay Blocks. H. H. Macey. (Transactions of the British Ceramic Society, 1939, vol. 38, Aug., pp. 469–475). The author reports on an investigation of some factors which affect the safe rate of drying of fireclay blocks 10 in. × 10 in. × 6 in. From the results obtained he concludes that: (1) Maturing the clay in the moulded piece is definitely beneficial to the drying. (2) The greatest safe rate of drying depends on the temperature at which it is performed, and there is an optimum temperature at which drying may proceed at the fastest rate. This temperature will naturally be expected to vary from clay to clay. (3) The safe rate of drying increases with decrease of moisture content. Thus, during the maturing of a moulded block, strict prevention of drying is unnecessary, and for the absolute minimum time schedule of drying the rate should be increased as the drying proceeds.

The Effect of Hydrocarbon Gases on Refractory Materials. Part II. Further Study of the Effect of Methane on Refractory Materials. E. Rowden and A. T. Green. (Transactions of the British Ceramic Society, 1939, vol. 38, July, pp. 418–424). In Part I. of this series (*see* Journ. I. and S.I., 1938, No. II., p. 1 A) it was shown that passing methane over certain fireclay bricks held at a temperature of 795° C. caused their disintegration. As the decomposition of methane increases with increasing temperature the action of the gas at temperatures above 795° C. was also studied and an account of this investigation is here presented. The results

obtained at a temperature of 880° C. may be summarised as follows : After 30 hr. treatment two firebrick specimens had developed cracks. The first firebrick sample disintegrated after 37½ hr., the second after 44½ hr., the third after 52 hr., whilst after 66½ hr. pieces had flaked off the fourth firebrick specimen. After a total time of 160 hr., of the original seven samples two silica specimens and one firebrick specimen were still whole and unattacked except for carbon discoloration throughout.

The Effect of Hydrocarbon Gases on Refractory Materials. Part III. A Study of the Effect of Coal Gas on Refractory Materials. E. Rowden and A. T. Green. (Transactions of the British Ceramic Society, 1939, vol. 38, July, pp. 425–434). The authors report on an investigation of the effect of passing coal gas over refractory bricks at high temperatures. At 500° and 800° C. no disintegration of the specimens was noted. The only effect was the discoloration of the test-pieces, which was more intense at 800° C., and the formation of a few carbon spots in a few of the firebrick specimens. At 900° C. disintegration and cracking of the firebrick specimens took place, one sample being disintegrated in 72 hr., whilst other firebrick samples were slightly attacked and cracked. The silica specimens resisted cracking and disintegration. The authors point out that the condition of the interior of the furnace tube is a factor which might affect the results obtained, and that no account has been taken of it. They state that more experiments must be completed before a satisfactory explanation of the disintegration at 900° C. can be put forward.

An X-Ray Study of Alumino-Silicate Refractories. A. H. Jay. (Transactions of the British Ceramic Society, 1939, vol. 38, Aug., pp. 455–460). The constitution of fired clay products as used in steelworks has been studied by X-ray methods of analysis. The constitution is expressed by the relative amounts of residual quartz, γ-alumina, cristobalite and mullite. Fundamental information regarding the crystalline changes occurring during firing was obtained from laboratory and commercially fired clays. It has been found possible to estimate the firing temperature, between 1000° and 1300° C., of commercial fireclay products.

Refractories in Industrial Service. W. J. Rees. (Proceedings of the Cleveland Institution of Engineers, 1938–39, No. 3, pp. 87–103). The author considers in detail the characteristics of fireclay, silica and basic refractories, pointing out the advances which have been made in recent years.

FUEL

(Continued from pp. 254 A–256 A)

Superposed and Low Pressure Turbines for Steel Mills. L. E. Newman. (Iron and Steel Engineer, 1939, vol. 16, Aug., pp. 54–57). The author examines the advantages and disadvantages of installing either a high-pressure turbine or, when waste steam is available at about atmospheric pressure, a low-pressure condensing turbine as a means of utilising to the full the steam produced by a steelworks boiler plant.

Washability Studies of the America and Pratt Coal Beds at Gorgas, Ala. B. W. Gandrud and G. D. Coe. (United States Bureau of Mines, 1939, July, Report of Investigations No. 3458). The authors present the results of chemical and screen analyses and sink-and-float tests made on samples of coal from the America and Pratt beds at Gorgas, Alabama.

Swelling Pressures during Carbonisation. (Coke and Smokeless-Fuel Age, 1939, vol. 1, Aug., pp. 98–102). The applicability of laboratory test results concerning the swelling pressure of coking coal to full-scale coke-oven practice is discussed and those methods of testing in which the coal is heated on one side only are criticised. A number of curves are presented which show the changes in pressure on the oven wall during the coking period for different mixtures of coal. The pressure-measuring apparatus designed by F. Ulrich (*see* Journ. I. and S.I., 1939, No. I., p. 264 A) is described. From the data obtained with this apparatus it is observed that the maximum swelling pressure of a blend is generally approximately equal to the resultant of the pressures set up by the several constituents.

The Determination of Coke Yield and the Volatile Matter of Solid Fuel. W. Radmacher. (Fuel in Science and Practice, 1939, vol. 18, Aug., pp. 228–246). The author describes his investigation of a new method, using an electric furnace, for determining the quantities of coke and volatile matter produced from coal. It is proposed that the new method should supersede that prescribed in German Engineering Standard 3725, which was derived from the Bochum test. He describes in detail the crucibles and the electric furnace used and compares the results of numerous tests on several German coals carried out by the old and new methods; these results are in very close agreement. This investigation was also described in Glückauf, 1938, vol. 74, July 23, pp. 628–633 (*see* Journ. I. and S.I., 1938, No. II., p. 195 A).

A New Commercial Low Temperature Carbonisation Plant. (Coke and Smokeless-Fuel Age, 1939, vol. 1, Aug., pp. 81–86). An

illustrated description is given of a low-temperature carbonisation plant recently completed at the Bestwood Colliery of Suncole (Nottingham) Ltd. The plant includes horizontal rotating retorts and it is capable of producing 300 tons of smokeless fuel per day from the treatment of 450 tons of non-coking coal.

Hydrogenation Tests on Canadian Coal. T. E. Warren, K. W. Bowles and R. E. Gilmore. (Industrial and Engineering Chemistry, Industrial Edition, 1939, vol. 31, Aug., pp. 1021–1025). The authors describe some laboratory-scale hydrogenation tests on nine Canadian coals of different rank ranging from medium-volatile bituminous coal to lignite. A sample as used for commercial hydrogenation in England was also tested as a standard of comparison; this yielded 71·5% of primary oil. Two of the Canadian coals yielded 77·2% and 73·8% respectively, and the lowest yield of all the coals tested was 53·3% of primary oil.

PRODUCTION OF IRON

(Continued from pp. 257 A–259 A)

New Blast-Furnace at the Cleveland Works of Dorman, Long & Company, Limited. (Iron and Coal Trades Review, 1939, vol. 139, Sept. 1, pp. 297–302). A detailed and illustrated description is given of the blast-furnace which has recently been completed at the Cleveland Works of Dorman, Long & Co., Ltd. The production of this blast-furnace is 2800 tons of pig iron per week. Great attention has been paid to the design and layout of the auxiliary equipment as well to the use of regulators and other instruments to ensure the efficient working of the furnace.

Blast-Furnace Plant. B. B. Frost. (Steel, 1939, vol. 105, Aug. 7, pp. 60, 83). The author describes some improvements in the equipment for the handling of ore at a small isolated blast-furnace plant at Ashland, Kentucky. The interesting feature of the improvements is the use of petrol-electric vehicles with a tippable container for conveying the ore from the ore bins to the skip of the charging hoist.

Aiding Small Furnaces. G. B. Garrett. (Steel, 1939, vol. 105, July 31, pp. 48–51). The author describes how some improvements were made to the efficiency of a small blast-furnace plant at Ashland, Kentucky. The heat storage capacity of the stoves was increased by inserting 3½-in. dia. fireclay spheres in the checkers. Steinbart pressure burners were fitted to the stoves and a new gas-washing plant was put in.

Blast-Furnace "Air-Conditioning." (Iron and Steel, 1939, vol. 12, Sept., pp. 709–711). An illustrated description is given of a dehumidifying unit installed at the blast-furnace plant of the Woodward Iron Co., Birmingham, U.S.A. This has also been described in Iron Age, 1939, vol. 144, July 20, pp. 38–39. (*See* p. 257 A).

Stakhanovite Methods in the Operation of a Blast-Furnace Works. P. Gorlov, A. Tkach and F. Khil'kevich. (Stal, 1939, No. 1, pp. 1–9). (In Russian). A number of improvements in equipment and operational control effected at the Krivorog blast-furnace plant are described. Attention has been paid to the steady working of the furnace by adopting a planned rate of charging and charging sequence and a corresponding blast control. A more uniform moistening of the ore was achieved by spraying it with water in the truck discharging hoppers instead of in the skips. Other improvements included a modification of the coke screening plant and the provision of a recording instrument to register the working of the McKee distributor. A machine has been constructed for piercing

the iron notch. In conclusion, the removal of scaffolding from blast-furnace shafts by blasting is described.

Progress in Blast-Furnace Research. J. B. Fortune. (Iron and Steel, 1939, vol. 12, Aug., pp. 665–669). After explaining the organisation of the committees at work in Great Britain on blast-furnace research and enumerating the reports published since 1927, the author gives an account of the more important problems that are still being investigated. With regard to coke, work is now in progress on the classification of coking coal and the determination of the physical properties of coke, and tests are being devised to determine the effect of combustibility upon (*a*) the maximum temperature of coking, (*b*) the soaking time at any such temperature, (*c*) the rate of carbonising, and (*d*) the particle size of the charge. Gas flow and the laws governing the passage of gas through columns of broken solids, blast-furnace reactions, slag systems, non-metallic inclusions in pig iron, applications of blast-furnace slag and blast-furnace refractories are all subjects on which research work is being directed.

Blast-Furnace Gas Flow. H. W. Johnson. (Iron Age, 1939, vol. 144, Aug. 31, pp. 28–31). The author discusses the changes in temperature and flow of the gases in No. 5 blast-furnace at the works of the Inland Steel Co. He reproduces tables and graphs of data obtained by a temperature survey taken over a long period by means of thermocouples inserted at four equidistant points in a plane about 10 ft. below the stock line and correlates these figures with the daily production, the volume and temperature of the blast and the analyses of the iron and slag.

Mud Gun Redesigned. (Iron Age, 1939, vol. 144, Aug. 24, p. 47). A description is given of the Bailey electric-plunger fireclay gun which is used for plugging the tap-hole of a blast-furnace. The clay barrel holds 9·6 cu. ft. of clay, which is extruded under a pressure of 600 lb. per sq. in. at the nozzle. Under normal conditions a tap-hole can be stopped in 40–45 sec.

The Disintegration of Iron Ore by Carbon Monoxide. W. Baukloh and F. Jaeger. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, Aug., pp. 65–67). In the process of reducing iron ore with carbon monoxide the formation of carbon from the decomposed gas causes the lumps of ore to increase considerably in size with consequent decrease in mechanical strength. In this paper the authors report on their investigation of this loss of strength after treating samples of twenty-five different German ores for 30 and for 60 min. with carbon monoxide at 550° C. The compressive strength of the samples before and after treatment was measured. Graphs drawn from the data obtained showed that there was no definite relationship between the strength before and after the test. It was observed that the more porous ores showed the greater loss of strength; some ore in fact disintegrated to powder after a very short period of treatment.

Experimental Production of Ferro-Silicon in a 930 cu. m. Capacity Blast-Furnace. V. Voronin, K. Shpel'ti and C. Muzykanskiy. (Stal, 1939, No. 2, pp. 1–6). (In Russian). The experimental production of ferro-silicon and its subsequent casting in a casting machine were tried before stopping the blast-furnace for a complete overhaul. The state of the furnace prior to the commencement of the experiment is described and the authors also deal with the raw materials and composition of the charge, furnace practice during the production of the ferro-silicon, losses of the ferro-alloy in the ladles and casting machine, the economics of the process and with the final stopping of the furnace. The experiment is regarded as satisfactory. A total of 15,996 tons of 10% ferro-silicon were produced during the 44 days of operation. The slag used should contain 10% of alumina and 43–46% of lime. The blast should be as hot as possible (850–750° C.). The use of a higher blast temperature may make it possible to work with a more acid slag and consequently to increase the silicon content of the alloy to 15–18%. The slag should amount to 0·75 ton per ton of alloy. Additional water-cooling of some parts of the furnace is recommended.

Some Fundamental Questions Connected with the Production of Iron Directly from Ores. Yu. Tishbeyn. (Stal, 1939, No. 2, pp. 6–12). (In Russian). The author deals with the factors which have to be taken into account when considering the low-temperature reduction of iron ores, *e.g.*, the reducing agent (hydrogen, carbon monoxide or mixtures of the two or natural gases rich in hydrogen; or solid reducing agents), suitable temperatures, the rate of reduction and the problem of regenerating the reducing agent. Possible methods of ensuring contact of the ore with the reducing agent and of the final separation of the metallic from the non-metallic phase are considered.

Porous Anti-Frictional "Cast" Iron Produced from Powder. M. Yu. Bal'shin and N. G. Korolenko. (Vestnik Metallopromyshlennosti, 1939, No. 3, pp. 34–41). (In Russian). Instead of using the rather expensive carbonyl iron powder in the production of porous bearings, a process has been developed which enables the production of the bearings from powder produced by grinding cast-iron cuttings or other small scrap. Either white, grey or malleable cast iron may be used by employing slightly modified techniques. The various stages of production, *viz.*, choice of raw materials, grinding, preliminary annealing of the powder, mixing, pressing, sintering and sizing, are described. White or grey cast irons of the following composition are preferred: Carbon 2·5–3·5%, silicon 0·8–1·7%, phosphorus up to 0·3%, manganese up to 0·8%, and sulphur 0·03–0·08%. Additions of iron powder, iron oxide, graphite, copper, zinc, &c., may also be made. The preliminary graphitising annealing should be carried out at 750–900° C. Pressing is effected (depending on the porosity required) at a pressure of 2,000–5,000 kg. per sq. cm. The sintering is carried out at about 1,100° C.

The porosity of the bearings may be between 20%and 35%. Hot pressing may also be used. The hardness of the porous material may be varied between 20 and 70 Brinell. The resistance to bending is about 17–18 kg. per sq. mm. Preliminary tests showed that the bearing and wear-resisting properties of the material were very good.

Iron 99·99 Per Cent. Pure. (Iron Age, 1939, vol. 144, July 13, p. 89). A brief description is given of the process of preparing chemically pure iron which has been developed by T. D. Yensen at the research laboratories of the Westinghouse Electric and Manufacturing Co. Up to 99·99% purity has been achieved. The spectrum of this iron is used as a standard for comparison with the spectra of commercial irons and steels.

The Primitive Smelting of Iron. T. A. Rickard. (American Journal of Archæology, 1939, vol. 44, No. 1, pp. 85–101). The author reviews the early history of ironmaking, giving evidence for concluding that the first smelting was done in Asia Minor about 1414 B.C., and describes the small and primitive furnaces and bellows which were, and in some districts still are, used by the natives in Africa.

R. Forester Mushet. (Alloy Metals Review, 1939, vol. 2, June, pp. 61–64). A short historical account is presented of the life of R. Forester Mushet (1811–1891) and his metallurgical discoveries, in which particular reference is made to his work on tungsten alloys which led to the discovery of self-hardening steel.

Statistical Diagrams of Sweden's Iron Trade. C. G. Carlsson. (Jernkontorets Annaler, 1939, vol. 123, No. 5, pp. 222–226). The author presents three diagrams which illustrate the import, home consumption and export of pig iron, scrap and semi-finished and finished steel products for Sweden in the years 1900, 1913 and 1937.

The Iron and Steel Industries of Europe. C. W. Wright. (United States Bureau of Mines, 1939, Economic Paper No. 19). The author presents a comprehensive survey of the iron and steel industries of Europe, dealing with each country separately.

FOUNDRY PRACTICE

(Continued from p. 260 A)

A.R.P. for Cupola Furnaces. (British Cast Iron Research Association, 1939, Aug., Special Publication No. 4). In this publication recommendations are made for the shutting-down of cupolas and for the screening of glare during air raids and during night work. It is recommended that on receiving a raid warning the blast should be shut off. The metal and slag should be drained from the well, poured down and covered with sand. The metal tap-hole should be closed but the slag hole may be left open. The cover plates on two tuyeres should be opened. Some drawings are presented of suitable anti-glare covers for cupola tops.

The Open-Hearth Furnace for Melting Malleable Cast Iron. G. R. Shotton. (Foundry Trade Journal, 1939, vol. 61, July 27, pp. 58–59; Aug. 3, pp. 79–81). The author discusses the design and operation of a 15-ton open-hearth furnace used for the melting of malleable cast iron. The high capital cost of such a furnace is a serious disadvantage, as, in addition to the cost of the furnace itself, gas-producing plant also has to be installed. It is also necessary to maintain its temperature fairly close to the melting temperature when not in operation so as to prevent spalling of the silica bricks. The furnace can be operated continuously for long periods, and will, in fact, yield better results under such conditions. Since the supply of molten metal for the foundry is intermittent, it precludes the use of a fully-mechanised continuous moulding system. Under certain conditions this may be a disadvantage. On the other hand, it supplies a large bulk of metal which is all of a uniform analysis. It admits of a close control of analysis. Melting losses are fairly constant, but when variations do occur, the analysis can be corrected before tapping the metal. The molten metal can be superheated to suit foundry requirements by holding the charge in the furnace until the required temperature is reached; during this period the slag layer covering the metal will prevent any serious oxidation of the charge. Close supervision and technical control are essential owing to the somewhat complex nature of the open-hearth and gas-producer plant. In conclusion, the author considers that the open-hearth furnace is comparatively cheap to operate when worked at near its maximum capacity, and it might be considered an economical proposition when operated down to about half capacity. On smaller outputs, however, the operating costs may quickly become prohibitive.

Atmosphere Gases for Malleable Iron Annealing and Their Application. J. Dow. (Transactions of the American Foundrymen's Association, 1939, vol. 47, pp. 209–223). The author

describes methods of producing decarburising, neutral and carburising gases used in the production of malleable cast iron, and then reports the results of tests on as-cast and machined specimens of white iron which had the object of determining how the rate of graphitisation was influenced by the different gases. He found that a carburising gas slightly increased the rate of graphitisation of the surface layer of a machined specimen, and a decarburising gas markedly reduced this rate. The examination of unmachined specimens showed that the rate of graphitisation was slower in the sub-surface layer than in the core, irrespective of the type of gas used. In conclusion, the author discusses annealing-furnace design with special reference to the position of the gas inlet and the effect of leaks.

The Properties of Resin Bonded Cores. E. Pragoff, jun. (Transactions of the American Foundrymen's Association, 1939, vol. 47, pp. 97–116). Selecting a high-melting-point pine-wood resin as typical of the improved resinous core binders now on the market, the author presents a series of studies on the more important properties of resin-bonded cores; he describes how they may be produced and how their properties may be controlled in actual practice by an intelligent use of resinous binders. The results of the studies show that resinous binders become more effective the more finely they are ground, and that, with proper mixing and baking at temperatures ranging from 300° to 500° F., the strength and hardness can be controlled by adjusting the amount of the binder, the moisture content and the length of the baking time. Resinous binders are specially suitable with sands with a high clay content and with reclaimed sands. The author also describes a method of preparing specimens of cores in the form of 1-in. cubes.

Producing a Large Iron Casting by the Randupson Process. G. Longden. (Foundry Trade Journal, 1939, vol. 61, Sept. 7, pp. 169–170). After briefly discussing the advantages of the Randupson system of moulding in which the moulds are made of a mixture of silica sand and cement with water added, the author describes in detail the preparation of a mould for casting a haulage drum for a slipway. This drum measured 11 ft. 6 in. long × 7 ft. 8 in. in inside dia.; the wall thickness was 3½ in. and it weighed 20½ tons.

Iron Lining Fused Centrifugally to Steel Brake Drum Shells. A. H. Allen. (Steel, 1939, vol. 105, Aug. 7, pp. 46–50). The author describes the plant and processes used by the Centrifugal Fusing Co., Michigan, for manufacturing automobile brake drums. This process was also described in Foundry, 1939, vol. 67, June, pp. 30–33, 100, 102. (*See* p. 194 A).

Transport Appliances in American Foundries. H. Allendorf. (Giesserei, 1939, vol. 26, Aug. 25, pp. 438–444). The author gives an illustrated account of the various types of appliances used in American foundries for the transportation of materials. He points out that every effort is made to relieve the operative of heavy physi-

cal labour, and then describes sand transporters and belt conveyors in the Chevrolet foundry, and pneumatic, electric and mechanically operated lifting gear in medium-sized and small foundries. Reference is also made to mechanical aids for charging the cupolas.

The Problem of Economic Foundry Production. E. Ronceray. (Proceedings of the Institution of Mechanical Engineers, 1939, vol. 141, Sept., pp. 475–486). The author describes methods of improving the production of foundries in an economic manner with particular reference to mechanical transport. He discusses in detail methods of stocking, preparing and conveying sand, the use of mould conveyors and the positions of the moulding machines relative to the conveyors. He is of the opinion that foundry transport has nothing in common with the problem of conveyor plant in general and that mechanical transport and other economies can be applied successfully in quite small foundries as well as in large works.

A Scientific Approach to a Foundry Problem. L. A. Danse. (Transactions of the American Foundrymen's Association, 1939, vol. 47, pp. 147–177). The author describes the investigation of the causes of cracks occurring in large cylinder-head castings at an American foundry. The cause was ascertained by inserting a number of thermocouples in the mould and recording the temperature changes as the casting cooled down. The cracks were found to be due to the very different cooling rates of different parts of the casting, and the trouble was remedied by using cooling coils in certain parts of the mould and other methods of obtaining a more even cooling.

PRODUCTION OF STEEL

(Continued from pp. 261 A–263 A)

Gary Plant of Carnegie-Illinois Steel Corporation. (Iron and Coal Trades Review, 1939, vol. 139, July 7, pp. 14–16). An illustrated description is given of the Gary Works of the Carnegie-Illinois Steel Corporation. These works comprise fourteen batteries of coke-ovens, twelve blast-furnaces, fifty-two open-hearth furnaces and three Bessemer converters, central rolling mills, merchant bar mills, and plate and tinplate mills with annealing and finishing departments.

Enlarges Open-Hearth Shop. (Steel, 1939, vol. 105, Aug. 14, pp. 40–41, 62–64). Some constructional details are given of the five new 150-ton open-hearth furnaces at the Indiana Harbor Works of the Inland Steel Co. The hearths at the foreplate level are 43 ft. long by 16 ft. wide and the depth of bath is 33 in. The furnaces can be heated by either oil or oil and coke-oven gas. The oil flow in gallons per hour is shown on a control panel and the pressure of the furnaces gases is controlled automatically by an electrically operated pressure controller and motor-operated louvres on the induced-draft waste-heat-boiler fan. The temperature of the bath is taken by a " Rayotube " element ; the sighting tube is pushed down in the bath below the slag level and a positive pressure of dry air in the tube prevents slag and molten steel from entering the tube.

Possible Methods of Increasing Production in Steelworks. G. Bulle. (Iron and Steel, 1939, vol. 12, Sept., pp. 717–722). An abridged English translation of a paper describing measures which could be taken in Germany to increase the production of steel by the Bessemer, open-hearth and electric-furnace processes. This paper appeared in Stahl und Eisen, 1939, vol. 59, July 13, pp. 809–814. (*See* p. 197 A).

Open-Hearth Improvements. L. S. Longenecker. (American Institute of Mining and Metallurgical Engineers, Open-Hearth Conference, Apr., 1939 : Steel, 1939, vol. 105, Aug. 14, pp. 44–46, 74). The author describes some improvements in the design and use of refractory-brick roofs and walls in open-hearth furnaces. These include a new type of suspended arch and a water-cooled door in which the exposed area is reduced. He also describes an auxiliary burner fitted in the front wall, and a scrap-charging machine of a telescopic type which, when extended, covers almost the whole length of the furnace ; in this machine the scrap rests on a series of trays which are withdrawn consecutively one under the other, thus dropping the scrap along the length of the furnace.

On the Means of Increasing the Life of Open-Hearth Linings. N. Dubrov and Ya. Drozdov. (Stal, 1939, No. 1, pp. 15–18). (In Russian). Conclusions arrived at as a result of observations on the influence of design on the life of open-hearth furnaces at the Andreev Works at Taganrog are described. Arches above the furnace doors appear to be unnecessary. A 12° slope of the front was satisfactory. The back wall should be inclined at an angle of 35–45° to the vertical. The rather expensive magnesite bricks were successfully replaced by making the wall (above slag level) of pipes filled with chrome-magnesite (fireclay binder) mixture, the spaces between the pipes being filled in with the same mixture. Roofs should be constructed of variable thickness (in transverse section), the more exposed parts being reinforced by thickening. Gas ports should be cooled by means of a cooling box rather than by cooling pipes. The walls of the vertical flues are more resistant when they are made to rest directly on the walls of the slag pockets.

The Life of Open-Hearth Furnace Bottoms. S. Lifshits. (Stal, 1939, No. 1, pp. 10–15). (In Russian). The author examines how furnace practice affects the stability of the bottoms and goes on to consider the causes of their destruction, the influence of the materials used for bottoms and the effect of the shape of the hearth. In conclusion, the laying and burning-in of an experimental bottom and results obtained with it are described. The life of the furnace bottom as affected not so much by the chemical composition of the dolomite as by its physical condition. The dolomite should preferably have a grain size of 5–15 mm. and must be freed from dust. The magnesite used should be dried immediately before it is mixed with the dolomite. The bottom must be correctly sloped towards the tap-hole, the slope increasing as one moves away from the tap-hole. The burning-in of the bottom lining should be carried out at a temperature of not less than 1680°, which should be raised to about 1700° during the last 4 hr. The amount of slag used for the subsequent impregnation should not be excessive. Experience with a furnace bottom constructed along the above lines (full details are given) has proved very encouraging.

Proceedings of Twenty-Second Open-Hearth Conference. (American Institute of Mining and Metallurgical Engineers, Open-Hearth Conference, Apr. 26–28, 1939). The Proceedings of the Twenty-Second Open-Hearth Conference organised by the American Institute of Mining and Metallurgical Engineers were opened at Cleveland, Ohio, by the General Chairman, L. F. Reinartz, who in his introductory remarks referred among other things to two questionnaires which had been sent out, one concerning burners for oil and natural-gas furnaces and the other on the standardisation of blue glasses for open-hearth furnacemen. The first paper, by R. A. Chaffin, dealt with the settlement of industrial grievances. He was followed by C. R. FonDersmith who spoke on the safety-first measures and organisation at the works of the American Rolling Mill Co. The

information obtained by the questionnaire on standardising blue goggles for furnacemen is given next, the answers of thirty-six companies being presented in tabular form. In another paper on safety-first, A. P. Miller showed how to analyse the history of an accident and laid down some practical safety regulations for workers at the casting pit. This was followed by H. B. Emerick, who dealt briefly with the training of metallurgists as observers to check the procedure in the melting shop. A. M. Morton spoke next on the trend of the design of the open-hearth furnace bottom. This was followed by a paper on research and development of open-hearth refractories by L. E. Smith, who stressed that steelworks should have their own laboratories with facilities for making acceptance tests on refractory bricks. A. V. Leun then dealt with some problems confronting the makers of refractories for open-hearth furnaces, pointing out that the steelmaker now wanted a better brick for the furnace roof, if possible one capable of withstanding a face temperature of 3300° F. or even higher. This completed the first day of the Conference. The second day began with a joint session of the Open-Hearth and Blast-Furnace and Raw Materials Committees, at which R. Urquhart delivered a paper on how the quality of an ingot is affected by pig-iron conditions. In this he discussed the difficulties the steelmaker had to contend with, such as variations in the analysis and temperature of the molten pig iron that he received from the blast-furnaces. This was followed by two papers on the same subject by E. L. Ramsey and E. H. Leathers. The former also referred to the necessity of the molten iron for the steel furnace to be of uniform analysis and at as high a temperature as possible. The latter author stated that the greatest difficulty was experienced in working the open-hearth furnace when the iron was high in both silicon and sulphur. C. J. Fleisch then contributed a paper on meeting the requirements of the open-hearth furnace at the blast-furnace; in this he dealt with the costs incurred in changing the composition of the iron supplied to the steel furnace. In this connection he gave examples of the economies effected by charging open-hearth slag into the blast-furnace, but if the steelmaker demanded lower manganese and phosphorus in the iron the use of the open-hearth slag would have to stop, with consequent loss. The concluding paper of the series on the effect of the quality of the molten iron upon the steelmaking process was by L. H. Nelson; the conclusions reached by this author were: (1) Low-silicon iron is conducive to poor quality steel and erratic furnace operation; (2) high-sulphur iron has the same effects as stated in (1); (3) molten iron at a low temperature has a detrimental effect; (4) manganese over 1·50% is desirable; (5) high silicon is undesirable; and (6) the following analysis is recommended for smooth furnace operation and to produce a good quality killed steel: Carbon over 4·0%, silicon 0·90–1·10%, sulphur 0·035% max., manganese 1·60–1·90%, phosphorus 0·400% max., and the casting temperature should be

over 2700° F. Two papers on ladles were then presented. In the first J. McCarney described the closed-top 80-ton ladles used by the Jones and Laughlin Steel Corporation for conveying basic Bessemer iron. In the second paper F. L. Lindemuth compared the advantages and disadvantages of mixer-type with those of small ladles. A. C. Keller discussed next the composition of iron for blowing in the converter in the duplex process of steelmaking. This was followed by two papers on the use of open-hearth slag in the blast-furnace, the first by C. L. Labeka and W. C. Kitto and the second by F. G. Norris. The proceedings of the last day of the Conference commenced with a paper by H. K. Work and M. H. Banta in which they described the 1500-lb. experimental open-hearth furnace of the Jones and Laughlin Steel Corporation. They were followed by W. C. Kitto, who gave some details of the construction and operation of a new 135-ton open-hearth furnace at the works of the Pittsburgh Steel Co. The next group of papers to be presented were on the subject of temperature measurement. In the first of these M. J. Bradley described the "Rayotube" method of measuring the temperature beneath the surface of the molten metal. E. D. Martin discussed next some practical tests on the "Rayotube" temperature measuring device, and methods of calibrating this instrument. In the third paper of this group C. E. Sims described the quick-immersion thermocouple referred to in the Iron and Steel Institute Special Report No. 25. The last paper of this group was by G. R. Fitterer, in which he related some of his experience with a carbon/silicon-carbide thermocouple for measuring molten steel temperatures. Two papers were then presented on improvements to open-hearth furnaces; in the first J. M. Crowe described the Crowe auxiliary slag pocket and in the second L. S. Longenecker (*see* p. 323 A) gave details of four improvements to open-hearth furnaces, as follows: (*a*) a design of suspended-arch roof which eliminates the front wall of the furnace; (*b*) furnace doors operated by bogies; (*c*) an auxiliary burner in the front wall to accelerate the melting of the scrap; and (*d*) an improved type of open-hearth furnace charging machine. J. Chipman then gave an outline of the researches on slags and the reactions of slags with molten iron, which are now being carried out at the Massachusetts Institute of Technology. He was followed by E. C. Barringer, who discussed the proportion of light to heavy steel scrap which came on the American market and said that during the last two years the amount of light scrap available for steelmaking was increasing and that of heavy scrap decreasing. The last paper to be read at the Conference was one in which J. D. Sullivan presented some tables showing the percentages of residual nickel, copper, tin, manganese and chromium in open-hearth steels as reported by a number of American steel producers.

Prescribed Working of the New Open-Hearth Shop at the Kirov Works. L. Agre and N. Molotkov. (Stal, 1938, No. 12, pp. 18–35).

(In Russian). The plans covering the organisation and management of the new open-hearth shop are described in detail. Tests on the furnaces showed that after the elimination of certain unsatisfactory features, the thermal capacity during the period of charging could be raised to 32 million cal. per hr. Plans for the heat supply and the working of the whole process have been developed. Analyses of available data were used to establish the output of the furnace per hour depending on the weight of the charge, changes in the output capacity during a campaign and the duration of a heat for different types of steel. Diagrams showing the time of stoppages of the furnace for hot and cold repairs and repairs to the hearth have been constructed. Plans were also drawn up for the movement of rolling stock supplying raw materials, for teeming and for the removal of ingots, moulds, slag, &c. A number of changes in the layout of tracks were required. In conclusion methods of time-keeping and payment are suggested.

Investigation of the Melting Process in Large Open-Hearth Furnaces with a Deep Bath. P. Ivanov and L. Katsen. (Stal, 1939, No. 2, pp. 13–17). (In Russian). The experimental data discussed in this article were obtained from open-hearth furnaces ranging from 120 to 400 tons in capacity and with a depth of bath of from 900 to 1700 mm. The following factors which affect the rate of elimination of the carbon were studied : (1) Depth of bath, (2) thermal capacity of the furnace, (3) composition and properties of the slag, and (4) the effect of manganese. The chief factor which lowers the rate of elimination of the carbon as the depth of the bath is increased is the reduction in the reactive surface area of the bath per unit weight of charge. This may be counteracted by increasing the rate of heat supply to the furnace, which will favour elimination of the carbon by raising the rate of diffusion of the ferrous oxide from the slag into the metal. The fluidity of the slag should be increased by increasing its basicity. Finally, ferro-manganese should not be added during the boil, as this lowers the rate of carbon elimination.

The Effect of Temperature on the Equilibrium between Carbon and Oxygen in Molten Steel and in a Gas Phase. G. Phragmén and B. Kalling. (Jernkontorets Annaler, 1939, vol. 123, No. 5, pp. 199–218). (In Swedish). The authors review the history of the investigation of the carbon-oxygen equilibrium in molten steel and between the carbon monoxide and the carbon dioxide present in the gases in contact with the steel. A true knowledge of this equilibrium must be gained in order fully to understand the refining processes. The numerical values of the carbon-oxygen product were obtained first from a study of the open-hearth process, and subsequent laboratory experiments resulted in a value of 0·0025 being obtained, which is in close agreement with that derived from full-scale investigations. The authors found experimentally that the influence of heat on the equilibrium is quite small, which also confirms the conclusions obtained by calculation. The authors also complete the equilibrium

diagram showing the composition of the gas phase in the iron-carbon-oxygen system under a total pressure of 1 atm. and in the presence of different condensed phases. A bibliography of seventy-two references is appended.

Rimming Steels. R. H. Myers. (Swansea Technical College Metallurgical Society, Jan. 28, 1939). The author explains the equilibria associated with the reactions between iron, carbon and oxygen in the solid, liquid and gaseous phases at different temperaures and pressures with particular reference to Hultgren and Phragmén's work on this subject. (*See* Journ. I. and S.I., 1939, No. I., p. 214 A). He then considers observations made during the freezing of rimming-steel ingots, explains the factors tending to promote and reduce the evolution of gas and relates these to the theoretical aspect previously discussed. In conclusion the author discusses the factors affecting the quality of a rimming-steel ingot, pointing out that fast teeming, hot moulds and high-temperature steel all tend to produce blow-holes near the skin, whilst bottom-pouring, by virtue of the slow rate of rise with a consequent greater chilling effect on the steel, tends to produce more deeply seated blow-holes as compared with direct pouring.

Sodium Fluoride in Steel Ingots. S. Herres. (Mines Magazine, 1939, vol. 29, Aug., pp. 416–418). The author examines the information available on the effects of adding fluorspar to steel in the basic open-hearth furnace and in the ingot mould. In the basic open-hearth furnace it lowers the melting point of the slag, thus permitting lower furnace temperatures and reducing the time for refining; it increases the fluidity of the slag, thus assisting the escape of gases from the metal; and it assists in the removal of sulphur and phosphorus by volatilisation and by slagging, either by direct action or by enabling a more highly basic slag to be used. In the ingot mould fluorspar tends to reduce segregation because it reacts with phosphorus and sulphur to form fluorides which are eliminated as gases; it increases the fluidity of any slag present and thus helps to bring the impurities to the top; it probably reduces the number of blow-holes by bringing to the surface bubbles of gas which form on the liquid particles of the sodium fluoride; it is also possible that the liquid sodium fluoride forms a cover on the ingot surface, thus retarding the rate of cooling of the steel.

Open-Hearth Slag Control. W. J. Reagan. (Iron Age, 1939, vol. 144, Aug. 17, pp. 31–38). The author describes a viscosimeter used at the works of the Edgewater Steel Co. to determine the fluidity of the slag in basic open-hearth furnaces. The viscosimeter is a split steel forging with a funnel at one end, from the base of which extends a horizontal tube 10 in. long and $\frac{1}{4}$ in. in dia. A spoonful of slag is poured into the funnel and the distance the slag travels along the tube before solidifying is a measure of the fluidity of the slag. With the aid of numerous tables and graphs the author relates the analyses of the steel and the slag to the slag viscosity at various stages

of the heat and shows that the viscosity readings are of great value in enabling a careful control of the carbon content of the product to be maintained.

Scrap Baling Plant. (Steel, 1939, vol. 105, Aug. 21, pp. 56–58). An illustrated description is given of a Diesel-engine-driven baling press for baling sheet-metal scrap and a conveyor, driven by the same engine, which loads the bales direct from the press into trucks. The Diesel engine can also be used for other purposes and it has proved an economic unit at a scrap-metal yard where baling is not done continuously.

Electric Furnaces and Their Application in the Steel Industry. O. Inman and H. A. Wainwright. (British Steelmaker, 1939, vol. 5, Aug., pp. 277–282; Sept., pp. 317–320, 323–324). The authors describe the design and principles of operation of electric furnaces used in the steel industry. In Part I. they deal with direct- and indirect-resistance furnaces. The former are those in which the heat is generated by the resistance offered to the passage of the current through the material to be heated and they include furnaces in which one piece is heated, or in which several pieces are heated as one charge, or in which the pieces are heated by immersion in a bath. The indirect-resistance furnaces are those in which the heat is transferred to the charge from some form of resistor adjacent to it. The authors also describe a resistance furnace of unusual but very efficient design. This is a vertical structure with the furnace at the top of a tower down the centre of which a heat-insulated tube passes from the base of the furnace to ground level. The furnace is intended for the annealing or normalising of strip steel, which travels up the tube, through the furnace, round a pulley at the top of the furnace, and returns through the furnace and down the tube to a coiling drum. During its passage down the tube the absorbed heat is transferred to the rising strip so that the treated material arrives at the coiler at a temperature very little higher than atmospheric. Some temperature control devices and the refractories for supporting the resistors are also described in this part. In Part II. the authors explain the principles of coreless induction furnaces, spark gap furnaces, and direct and indirect arc furnaces. They illustrate some of the electric furnaces at the works of Samuel Fox and Co., Ltd., and others at works on the Continent, and present diagrams and tables showing the heat balances, current consumptions, melting times, life of linings and weekly outputs of a number of furnaces from small laboratory size up to 5 tons capacity.

Melting of Steel *KhMA*4 in Electric Furnaces. A. Kotin and A. Kholodov. (Stal, 1939, No. 1., pp. 24–29). (In Russian). Steel *KhMA*4 is a nitriding steel with 0·35–0·42% of carbon, 0·30–0·60% of manganese, 0·17–0·42% of silicon, 1·45–1·65% of chromium, 0·40–0·60% of molybdenum, 0·70–1·10% of aluminium, $\leqslant$ 0·03% of sulphur, $\leqslant$ 0·03% of phosphorus and $\leqslant$ 0·20% of nickel. In the first section of the paper the authors examine statistical data

relating to practice and tests in order to trace the cause of the "columnar" fracture defect in the steel and factors affecting the impact strength. The conclusions arrived at were then verified experimentally, some observations finally being made on the control of a number of heats. It is concluded that the columnar fracture and the accompanying banded ferrite are due to heterogeneity of the metal, which in turn is caused by the precipitation of aluminium-bearing ferrite around the Al_2O_3 inclusions and to some extent around the MnS inclusions, which act as crystallisation centres. The more pronounced columnar fracture near the centre of the billets is due to temperature conditions during the solidification of the ingots which facilitate the separation of the aluminium-bearing ferrite and also favour a certain segregation of the Al_2O_3. A columnar fracture and an increased number of non-metallic inclusions increase the impact strength in test-pieces taken in the longitudinal direction. Sound fracture and good solution of the aluminium are obtained by acid melting. The steel should be thoroughly deoxidised before adding the aluminium during the tapping of the furnace.

Power and Electrode Consumption in Electric Furnaces. S. von Hofsten. (Foundry Trade Journal, 1939, vol. 61, Sept. 7, p. 174). An abridged English translation of an article which appeared in Teknisk Tidskrift, 1939, vol. 69, Jan. 14, pp. 14–17 is presented in which some particulars are given of experience gained in the working of a 14-ton and a 7-ton electric arc furnace in Sweden. (*See* p. 201 A).

High Frequency Melting at the Works of Turton Bros. and Matthews. (Iron and Steel, 1939, vol. 12, Sept., pp. 715–716). A brief illustrated description is given of the steel foundry of Turton Bros. and Matthews at Sheffield, where special quality steel castings are made. The equipment includes three H.F. furnaces of 1, 3 and 5 cwt. capacity respectively.

The Effect of the Gas Content of the Metal on the Soundness of the Ingots. N. Chuyko. (Stal, 1939, No. 1, pp. 19–23). (In Russian). Gas-metal equilibria in steel are briefly considered by way of introduction. Hydrogen and oxygen are the most undesirable gases, the latter resulting in an increase of the [FeO][C] product and the consequent formation and evolution of CO, while hydrogen cannot be readily eliminated from the metal. The partial pressure of the hydrogen in the metal increases during freezing, owing to the reduced solubility, and this may lead to porosity if the hydrogen content is greater than 0·001%. The partial pressure of nitrogen for the usual nitrogen contents may be neglected. The oxygen content as FeO should preferably be less than 0·003%. Gases, in particular hydrogen, evolved during the solidification of the ingot migrate into those parts which are the last to solidify (gas segregation); this movement favours the segregation of carbon, phosphorus, sulphur, FeO, &c., into the upper and central portions of the ingot. The presence in them of hydrogen leads to flakiness. Central

segregation and porosity are dependent on the degree of deoxidation of the steel (confirmed experimentally), *i.e.*, on the amount of FeO and, indirectly, of CO present. Statistical data for electric-furnace alloy steel showed that central porosity was greater in acid steel, owing to the lower degree of deoxidation, while on the other hand the total porosity, blow-holes and flakes were lower. A number of brief recommendations regarding furnace practice and teeming are appended.

Inclusions in Rimming Steel. J. G. Dun and J. F. Bekola. (Iron Age, 1939, vol. 144, Aug. 24, pp. 23–29; Aug. 31, pp. 36–38). In the first part of this article the authors study the occurrence of sulphide and silicate inclusions in rimming steel and present diagrams which show the different degrees of segregation in different planes along the length of the ingot, and illustrate the defects in deep-drawn steel sheet which are caused by inclusions. In the second part they describe a series of tests made by casting small bars of steel taken from the furnace, from the ladle and from the ingot mould. Specimens were prepared from these bars and examined under the microscope. The samples cast from the furnace were exceedingly clean, with only minute particles of oxides present; those cast from the ladle contained a wider variety of inclusions, which the authors classified as glassy, semi-glassy, opaque, dendritic and network types. The authors conclude by examining the mechanism of the formation of inclusions, which they find is governed by the two processes of chemical reaction and mechanical trapping.

Solidification of Rimming-Steel Ingots. A. Hultgren and G. Phragmén. (American Institute of Mining and Metallurgical Engineers, 1939, Contribution No. 112). This is a revised English translation of a paper published in Swedish in Jernkontorets Annaler, 1938, vol. 122, No. 8, pp. 377–453. (*See* Journ. I. and S.I., 1939, No. I., p. 214 A).

ROLLING-MILL PRACTICE

(Continued from pp. 267 A–270 A)

A Study of the Phenomenon of Spread in Rolling. J. Roux. (Revue de Métallurgie, Mémoires, 1939, vol. 36, June, pp. 257–270). In this mathematical discussion the author develops formulæ for calculating the amount by which steel will spread during the various stages of reduction in a rolling mill.

Recrystallisation and the Method of Rolling Structural Chromium-Nickel Steel. M. Vratskiy, P. Rozdymakha and G. Slobodyanok. (Stal, 1939, No. 1, pp. 30–38). (In Russian). A steel with 0·36% of carbon, 0·40% of manganese, 0·32% of silicon, 1·35% of chromium, 3·3% of nickel, 0·01% of sulphur, and 0·01% of phosphorus was used; in the experiments the actual deformations were effected under a press for low speeds, and under a drop hammer for high speeds. Rectangular specimens were used at various temperatures between 1200° and 700° C., the deformations ranging from 5 to 75%. The main object of the work was to determine the change of the grain size of the solid solution as a result of hot-working and to connect this change with the temperature, degree and rate of deformation. Some conclusions regarding suitable rolling practice and temperatures are drawn from the numerous experimental results obtained. Recrystallisation caused by low rates of deformation is characterised by a minimum in the relative grain-size curve at about 15% deformation and temperatures of 700° and 800°. At higher temperatures the grain size decreases at a diminishing rate as the deformation is increased. For large deformations, the most intensive decrease in grain size occurs at 1200–1100° C. Rolling should be completed at 850–800° C.

Luster-Ground Mill Rolls. R. J. Spence. (Machinist, 1939, vol. 83, Aug. 26, pp. 562–564). The author describes different grinding techniques employed to produce a highly polished surface on rolls for sheet mills. He criticises the " building up " method in which a fairly coarse-grained wheel is used for the rough grinding, followed by successive stages of grinding in which a wheel of finer grain and softer grade is used at each stage. He describes next a new grinding technique which is carried out in three stages and thus saves considerable time; this consists of rough-grinding with a No. 36 grain silicon-carbide wheel, smooth-grinding with a No. 60 grain wheel of the same abrasive and final-grinding with the same wheel trued up with a diamond dressing tool, the final cut on the roll having a depth of about 0·00025 in. with an extremely slow traverse.

Applications of Anti-Friction Bearings in Tube Mill Equipment. S. M. Weckstein. (Iron and Steel Engineer, 1939, vol. 16, Aug., pp. 30–39). The author discusses the design of roller bearings of different types for the various requirements of American mills for the rolling of seamless tubes.

Types of Lubricants Essential to Steel Mills. W. H. Mandy. (Iron and Steel Engineer, 1939, vol. 16, Aug., pp. 20–28). The author discusses the properties and applications in rolling mills of the following lubricants: (1) Black oils, (2) journal oils, (3) red engine oils, (4) pale oils, (5) turbine oils, (6) steam cylinder oils, (7) cup grease, (8) low-melting-point pressure gun grease, (9) high-melting-point pressure gun grease, (10) extreme-pressure grease, (11) extreme-pressure gear lubricants, (12) compound greases for heavy gears, (13) hard tallow or grease for the necks of cold rolls, and (14) grease for the necks of hot rolls.

Oils in Every Steel Mill. H. D. Kolb. (Blast Furnace and Steel Plant, 1939, vol. 27, July, pp. 665–668). The author discusses the correct types of oil to use for lubricating rolling-mill equipment such as cranes, ingot strippers, charging machines, ladle and ingot bogies, mill motors, steam engines and pneumatic tools. The lubrication of the roll stands is not dealt with in this article.

Rolling by the Method of Minimum Tolerances. M. Galemin. (Stal, 1939, No. 1, pp. 39–41). (In Russian). As has been pointed out, an appreciable economy in metal can be achieved by rolling sections, &c., on the small side but so that they just come within the minimum (negative) tolerance limits specified. The author mentions briefly some of the factors which have to be considered in rolling by this method and refers by way of examples to the rolling of round bars, angles and rails. A further advantage of this method is the longer life of section rolls. The reduction in mechanical properties of the rolled products is negligible.

Mill Features Bypasses. (Steel, 1939, vol. 105, Aug. 14, pp. 48–49, 71). A brief illustrated description is given of a new mill for rolling sections at the Weirton Works of the Weirton Steel Co. Three of the mill stands at these works can be quickly removed *in toto* and spare stands put in their place, an operation which does not hold up production as much as changing the rolls without moving the stands. The layout at this mill is such that in the movement of the material to be rolled certain stands where congestion may occur can be by-passed, the steel proceeding to another stand where the same operation can be performed.

Weirton Opens 29-in. Structural Mill. T. C. Campbell. (Iron Age, 1939, vol. 144, Aug. 24, pp. 44–46). The author presents an illustrated description of the new rolling-mill plant installed by the Weirton Steel Co., Weirton, Virginia, which includes three stands of 29-in. rolls for rolling large structural steel sections.

Problems in the Manufacture and Use of Steel Products in the United States. J. E. Lose. (American Iron and Steel Institute,

May, 1939 : Blast Furnace and Steel Plant, 1939, vol. 27, June, pp. 577–581, 586 ; July, pp. 680–685, 705–706). After dealing in general terms with the problems confronting the steelmaker by reason of the more exacting demands of industrial users, the author discusses the subject by grouping the products into the following classes : (*a*) Tinplate ; (*b*) sheet and strip ; (*c*) bars and semi-finished steel. In the second part the author deals with the difficulties encountered in the manufacture of rails ; railway wagon wheels, axles and bodies ; wire, and tubes.

Manufacture of Boiler Plate. W. G. Theisinger. (Iron Age, 1939, vol. 144, Aug. 17, pp. 40–41). After outlining the history of the manufacture of boiler plate in the United States, the author describes some of the processes involved in the manufacture of the very heavy plates required for modern high-pressure boilers.

Tinplate Mills at Irvin Works of Carnegie-Illinois Steel Corporation. (Iron and Coal Trades Review, 1939, vol. 139, Aug. 11, pp. 193–194). An illustrated description is presented of the new tinplate mill, electrolytic pickling plant, annealing department, temper mill, shearing lines and the tinning machines at the Irvin Works of the Carnegie-Illinois Steel Corporation. (*See* p. 207 A).

New Tinplate Mill at the Irvin Works of the Carnegie-Illinois Steel Corporation. (Iron and Steel, 1939, vol. 12, Aug., pp. 671–676). An illustrated description is given of the new sheet mill and tinning plant for manufacturing tinplate at the Irvin Works of the Carnegie-Illinois Steel Corporation. (*See* p. 207 A).

Tinplate and the Canning Industry. W. E. Hoare. (Metallurgia, 1939, vol. 20, July, pp. 105–106). After comparing the advantages and disadvantages of manufacturing tinplate by the continuous cold-reduction and the " pack-rolling " processes, the author describes briefly how cans are made and the process of filling them.

Mechanisation of Thin Sheet Rolling Mills. A. Vitkin. (Stal, 1939, No. 2, pp. 23–31). (In Russian). Developments in sheet-rolling equipment are surveyed and some modern three- and two-high mills and their output capacities, soaking pits of the conveyor type, mechanised three-high roughing mills, finishing mills and accessory equipment are described.

How a Modern Works is being Developed for Rolling and Processing of Hot and Cold Rolled Strip Steel. (Sheet Metal Industries, 1939, vol. 13, Aug., pp. 989–993). A detailed and illustrated description is given of the strip mill and annealing furnaces at the works of Arthur Lee and Sons, Ltd., near Sheffield. Hot strip up to 18 in. wide, cold strip up to 24 in. wide and stainless steel up to 12 in. wide can be rolled.

Razor Blade Strip. (Iron and Steel, 1939, vol. 12, Aug., pp. 677–678). Following a brief review of the history of razor-blade manufacture in England an account is given of the processes of hot- and cold-rolling, shearing and grinding which are used in the manufacture of steel strip for making razor blades.

Review of Developments in Seamless Tube Manufacture. C. Ohlson. (Iron and Steel Engineer, 1939, vol. 16, Aug., pp. 14–18). The author traces the history of the development of the manufacture of seamless steel tubes with special reference to the Mannesmann and pilger processes. In conclusion he describes the two high-speed piercing mills installed in 1938 by the Youngstown Sheet and Tube Co. The first of these will take a solid billet up to 13 in. in dia. by 18 ft. long, and the second will take a pierced billet up to 15 in. in dia. by 26 ft. long.

Reconstruction of the Tube Mill of the Vereinigte Oberschlesische Hüttenwerke. E. Schoenawa. (Stahl und Eisen, 1939, vol. 59, Aug. 24, pp. 968–970). The author describes the original layout of the tube mills at the Vereinigte Oberschlesische Hüttenwerke, gives the reasons for deciding to convert the mills to the Stiefel process, and then describes the new layout and the results so far obtained.

Steelworks Distribution. (Electrical Review, 1939, vol. 125, July 28, pp. 113–116). An illustrated account is given of the electricity distribution system at the Ebbw Vale Works of Richard Thomas and Co., Ltd.

A Torque Indicator for Rolling Mills. (Iron and Steel, 1939, vol. 12, Aug., pp. 689–690). A description is given of a torque indicator for use in conjunction with mechanical couplings which are inserted between the driving set and the rolling mill. The indicator is produced by the Swedish General Electric Co., and it provides an additional protection to the mill machinery against dangerous overloads.

Rolling Mill Operation. R. J. Kryter. (Steel, 1939, vol. 105, Aug. 7, pp. 63–66). The author cites numerous examples of the advantages of using recording voltmeters, integrating recording wattmeters and positive recording oil flowmeters at steelworks and rolling mills.

Steel Plant Operation. R. J. Kryter. (Steel, 1939, vol. 105, Aug. 28, pp. 53–57, 64). The author describes how the study of current-time charts of the current consumed by mill motors, shears, cranes and other auxiliary machinery in a steelworks has led to the more economical operation of the plant.

PYROMETRY

(Continued from p. 88 A)

Rapid Temperature Measurements of Cast Iron with an Immersion Thermocouple. F. Holtby. (American Foundrymen's Association, May, 1939, Preprint No. 13). The author describes the difficulties which were encountered in developing suitable temperature-measuring equipment for research work at the foundry laboratory of the Minnesota University. He describes the optical pyrometers and the platinum/platinum-rhodium and tungsten/graphite thermocouples which were tried. The tungsten/graphite immersion-type thermocouple was found to be the most satisfactory. The author includes a description of the apparatus used for calibrating the thermocouples.

Potentiometers as a Means of Temperature Measurement and Control. W. R. L. Kent. (Metallurgia, 1939, vol. 20, May, pp. 31–34). The author describes in detail the theory of the potentiometer circuit and its application for the measurement of furnace temperatures and for the operation of valves controlling the supply of fuel gas to a furnace. The author finds from his extensive experience that two- or three-position switching devices are used in most cases, consequently the potentiometer instrument which is especially suitable for the operation of " make-and-break " contact mechanism is the best for this purpose.

Photo-electric Pyrometers. (Iron and Steel, 1939, vol. 12, Aug., pp. 680–683). An illustrated description is given of a photo-electric high-speed recording pyrometer which has many applications in steelworks practice. It is stated that the time lag between the occurrence and the recording of a change in temperature is less than half a second.

The Temperature of Gas—Its Meaning and Measurement. J. G. Bennett and M. Pirani. (Institute of Fuel, Symposium on Gas-Temperature Measurement, Dec., 1938 : Sheet Metal Industries, 1939, vol. 13, May, pp. 661–662 ; June, pp. 785–786). The authors endeavour to present a true picture of gas temperature in the light of modern physical theory using a minimum of terms unfamiliar to the engineer. In the first part they explain why a gas is very seldom in a state of thermal equilibrium, and some of the errors which occur in gas-temperature measurement because this fact is not taken into account. In the second part the authors consider the distribution of energy in a gas with particular reference to cases in which the energy is not equally distributed among different classes of energy carrier. Such classes are known as " energy flow traps," and

the " pseudo-temperature " is defined as the measure of the energy in an energy flow trap. They explain the significance of this pseudo-temperature and its relation to the temperature readings obtained by thermocouples and pyrometers.

Work-Temperature Control. (Steel, 1939, vol. 104, June 26, pp. 52–54). A description is given of an oil-fired slab-heating furnace 24 ft. long by 9 ft. wide for which a special method of temperature control was devised. This temperature control is effected by installing a radiation pyrometer (a " Rayotube ") in the furnace roof and sighted down through a tube on to the middle row of the three lines of slabs passing through the furnace. It was found that the " Rayotube " instrument gave more accurate readings and was more sensitive to temperature fluctuations than the thermocouple instrument previously used.

HEAT TREATMENT

(Continued from pp. 271 A–273 A)

Carburizing Compound. N. W. Elmer. (Steel, 1939, vol. 105, Sept. 4, pp. 48–49, 65). A description is given of the Redler conveyor system used at the foundry of the Chrysler Corporation for handling through the reconditioning plant the carburising compound used for case-hardening small parts. It is claimed that with the system in use important economies are effected and only one part of new compound need be added to six parts of used material to make up the absorbed carbon. A considerable saving in floor space as compared with older systems is an additional advantage.

Liquid Carburizing Baths. H. Solakian. (Steel, 1939, vol. 105, Aug. 21, pp. 51–54). The author describes the process of carburising steel in a bath containing sodium cyanide with additions of salts such as chlorides and carbonates of sodium, potassium, barium and strontium and reproduces curves showing how the depth of case increases with the time of immersion and the hardness increases with the carburising temperature.

Flame Hardened Lathe Beds. P. A. Abe. (Metal Progress, 1939, vol. 36, July, pp. 49–52). The author describes the theory and practice of flame-hardening as applied to the hardening of the ways of lathe-beds weighing up to 7½ tons. The lathe-bed is immersed in a water tank with the ways protruding above the surface and a manifold carrying six oxy-acetylene torches (one for each flat surface) travels along the ways. Jets of water move along about ¾ in. behind the flames and quench the heated surfaces.

"Five-Point" Deephard Steel. (Iron Age, 1939, vol. 144, July 13, p. 81). Some particulars are given of a steel specially heat-treated by a process developed by Foote Brothers Gear and Machine Corporation to which the name "Five-Point Deephard Steel" has been given. This process imparts a high surface hardness and a great depth of hardness with a gradual increase in hardness from the core to the surface. It is also claimed that the degree of uniformity of the surface hardness of steel treated by this process is excellent. Depending on the analysis of the steel, hardness values on the Rockwell C scale from 60 to 68 have been consistently obtained, and steel bars have been hardened to a depth of 0·320 in.

Protective Atmospheres. A. N. Ottis. (Canadian Metals and Metallurgical Industries, 1939, vol. 2, July, pp. 164–169). The author briefly describes the manufacture of protective atmospheres for heat-treatment furnaces by burning coke-oven gas or natural gas with an insufficient supply of air and then removing the moisture

until the water-vapour content does not exceed one-tenth of the hydrogen content. In the concluding part of his paper the author deals with the gases which will not decarburise a carbon steel. These include hydrogen and nitrogen obtained by decomposing ammonia. He also refers to a new portable instrument, the dew-point potentiometer, with which the dew-point of a sample of gas can be read directly on the instrument scale.

Equipment for the Production of Controlled Atmospheres. A. A. Shmykov. (Vestnik Metallopromyshlennosti, 1939, No. 4, pp. 38–52). (In Russian). The equipment for producing controlled atmospheres in the metallurgical department of the Automobile and Tractor Scientific Research Institute is described. It is designed primarily for the use of liquid ammonia, but town gas can also be employed. The equipment consists of five units : (1) The apparatus for the dissociation of the ammonia ; (2) a chamber in which the hydrogen formed by the dissociation of the ammonia is partially burnt, which also includes a gas scrubber and provision for a preliminary drying of the gas ; (3) a cooling chamber for removing the moisture ; (4) an adsorber for final drying ; and (5) an arrangement for the control of the gas flow and composition. The design and operation of the various units, their efficiency and possible alternatives are discussed.

Welding Stresses and their Removal by Annealing. N. N. Lipchin. (Vestnik Metallopromyshlennosti, 1939, No. 4, pp. 53–58). (In Russian). Some experimental results of measurements of stresses set up on welding in rings cut from cast 0·23% carbon steel cylinders are given. The rings were first annealed for 3 hr. at 900° C. and then machined to 592 mm. in internal diameter, 60 mm. in height and 28 mm. in wall thickness. A groove was cut on the inside or outside of the rings. These grooves were of 100 mm. side and 3–25 mm. deep. They were then filled up with weld metal and the stresses set up were determined by measuring the deformation which occurred when the rings were cut at a point opposite the weld. It was found that welds on the inside of the ring caused compressive and grooves on the outside caused tensile stresses, which reached a maximum for a depth of groove equal to 50% of the wall thickness of the ring. Hammering of the welds reduced the stresses appreciably. The stresses could be almost completely removed by low-temperature annealing (630–650° for 1 hr.), the magnitude of the original stress being without any influence on the effectiveness of the annealing treatment.

Heat Treatment—Its Effect on the Combined Carbon and Physical Properties of Wheel Iron. S. C. Massari. (Transactions of the American Foundrymen's Association, 1939, vol. 47, pp. 1–39). The author describes an investigation of the effect of heat treatment on a low-silicon grey cast iron similar to that used for making chilled railway-wagon wheels. The iron used contained silicon 0·50–0·60%, manganese 0·50–0·60%, total carbon 3·45–

3·65%, sulphur 0·14% max., and phosphorus 0·35% max. A large number of specimens were tested after heating at temperatures ranging from 500° to 1700° F. for various lengths of time up to 96 hr. The author came to the following conclusions: (1) No decomposition of the combined carbon occurs when the iron is heat-treated at temperatures up to 1000° F. for periods up to 96 hr. (2) Heat treatment at temperatures just below the critical range causes substantial decomposition of the combined carbon, the degree of breakdown being dependent upon the temperature. The decomposition of the iron carbide is practically complete at temperatures between 1200° and 1310° F. and after treatment at this temperature most of the physical properties are lowered with the exception of the impact strength. (3) When the heat treatment is carried out at temperatures above the critical range only a portion of the combined carbon is decomposed. (4) When the distribution of the graphite is normal the physical properties of grey cast iron are dependent upon the structural condition of the matrix, and the optimum properties are obtained when the matrix is entirely pearlitic.

High Strength Cast Steels. G. Delbart. (Transactions of the American Foundrymen's Association, 1939, vol. 47, pp. 179–194). The author considers those metallurgical factors affecting the properties of high-strength cast steels over which the foundryman can exert some measure of control; these factors include the superheating and pouring temperatures, the nature and purity of the materials charged, the composition of the steel and the addition of reducing elements. He also describes a "homogenisation" heat treatment for rectifying the structure if the cooling has been too rapid. This treatment consists of heating to a high temperature, but not exceeding that at the completion of solidification, and holding for some hours at that temperature. From the experiments with six different castings the author found that homogenisation at 2192° F. was much more rapid than at 1832° F. and the physical properties obtained after treating at 2192° F. for 8 hr. were much better than those obtained by treating at 1832° F. for 24 hr.

Completely Automatic Unit for Hardening and Drawing Axles. L. C. Powell. (Industrial Heating, 1939, vol. 6, July, pp. 596–598). The author describes a completely automatic heat-treatment plant for the hardening and tempering of axles for railway wagons and motor cars. This plant was also described in Iron Age, 1939, vol. 144, July 6, pp. 44–46. (*See* p. 272 A).

Contact Electric Hardening of Rails by the Method of Professor N. V. Geveling. D. M. Khayt. (Vestnik Metallopromyshlennosti, 1939, No. 4, pp. 59–66). (In Russian). In the method described electric current is conveyed to the rail-head through two contacts in the form of rollers made up of layers of copper-wire gauze bolted together, the edges of which are shaped to fit the rail-head. A space of 6 mm. is left between the two rollers. The circuit is thus

closed through the rail-head, which is heated by the current. The heads of the rails are hardened by rolling the rollers along them (speed, 2 mm. per sec.), followed by a stream of water for quenching. The results obtained in the experimental hardening of rail-ends by this method are described. After hardening, the ends were tempered in tubular electric resistance furnaces (300–350° for 10–12 min., judging from temper colours). Microscopic examination of the hardened layer showed that it consisted of an outer layer 0·2 mm. thick in which the ferrite network had remained undissolved, followed by a 5-mm. thick layer having a troostitic-sorbitic structure, and then a gradual transition to the original structure (fine lamellar pearlite surrounded by ferrite network). Tests showed that there was no tendency for the hardened layer to crack. A number of rails with hardened ends are at present undergoing service tests.

Temper-Hardening of Austenitic Steels Containing Boron. (Metallurgist, 1939, vol. 12, Aug., pp. 54–57). Some brief references are made to the work of a number of investigators of the iron-boron system and the hardening properties of austenitic chromium-nickel steels containing boron. This is followed by an abridged English translation of a paper by H. Cornelius entitled "The Hardening on Tempering of Austenitic Chromium-Nickel Steels Containing Boron" which appeared in Archiv für das Eisenhüttenwesen, 1939, vol. 12, Apr., pp. 499–505. (*See* p. 93 A).

Austempering on Production Basis. D. R. James. (Iron Age, 1939, vol. 144, Aug. 31, pp. 21–26). The author explains that "austempering" is the process of heating steel above the critical point, quenching it in a bath at a temperature between 350° and 750° F. for a predetermined length of time sufficient for the complete transformation to a non-martensitic structure, and then cooling to room temperature. He also gives examples of the application of Bain and Davenport's **S**-curves for determining the correct temperature of the quenching bath and the holding time, and describes a number of manufactured steel articles to which the "austempering" process has been applied with success.

Improved Tempering. (Steel, 1939, vol. 105, Sept. 4, pp. 42–46, 64–65). A description is given of the first heat treatment plant in which the process of "austempering" is carried out on a commercial scale (see preceding abstract). Tables are presented in which the physical properties of parts treated by the quench-and-tempering process and by "austempering" are compared.

WELDING AND CUTTING

(Continued from pp. 274 A–278 A)

The Value of Electric Arc Welding in Design and its Limitations. I. Harter, J. C. Hodge and G. J. Schressow. (Year Book of the American Iron and Steel Institute, 1939, pp. 186–241). By illustrating and describing a number of steel structures and bodies of unusual shape the authors point out the limitations of riveting and the advantages of welding. The examples show, however, that welding also has its limitations. All these limitations arise from the local application of welding heat, which occurs in all fusion welding processes. The authors discuss the progress made in overcoming the factors restricting the scope of welding and suggest that where difficulties in field welding cannot be overcome, study should be directed to breaking up the total design into units best adapted for completion in the shop, with stress relieving if necessary, and subsequent assembly in the field by bolting or riveting. They are of the opinion that the solution of the problems presented will be found by advancing the art of welding along the following lines: (1) Much higher welding speeds; (2) marked reduction in the volume of weld metal required in a welded joint, which will result in less distortion and a smaller stress-affected area; (3) the more general use of preheating and controlled cooling, permitting the use of higher-strength steels; and (4) the further development of steels possessing the optimum composition for strength and ready weldability.

A Suggested Investigation upon the Welding Arc. E. J. B. Willey. (Institute of Welding, Symposium on Arc Welding, Mar. 15, 1939: Welding Industry, 1939, vol. 7, Sept., pp. 318–319). The author studies the influence which the flux of a coated welding electrode exerts upon the arc in the electric welding process. He explains why the fall of potential across a column of gas which is carrying a current is not uniform in gradient but is in three parts, consisting of a large drop near the anode, another fall, much less than the first, across the main body of the arc, and a third fall, similar to the first, near the cathode. This non-uniformity causes a state of congestion to prevail among the ions and electrons at each electrode; this in turn gives rise to the so-called "space-charge" effect. Anything which will reduce this "space-charge" effect will diminish the potential drop and facilitate the flow of current, and anything which will furnish a good supply of charged bodies will therefore facilitate the passage of the arc. As the coatings of electrodes contain alkaline earth oxides (lime, baryta, strontia) which give off electrons with ease at 700–800° C., and iron

oxides or the oxides of heavy metals which emit positive ions at the same temperature, it will be seen that the action of the coating not only facilitates fusion and the formation of slag but also has a definite influence on the maintenance of a steady arc. The author suggests that further investigations should be undertaken by making simultaneous observations upon the voltage and current density by taking oscillographs, and upon arc splash by cinematography.

Welding Galvanized Sheets by Carbon Arc. E. W. P. Smith. (Iron Age, 1939, vol. 144, Aug. 24, pp. 48–49). **Galvanized Sheet.** (Steel, 1939, vol. 105, Aug. 28, pp. 50–52, 65). A brief description is given of the correct technique to employ for the welding of light gauge galvanised sheets using carbon electrodes.

Ignitron Control of Resistance-Welding Machines. (Engineering, 1939, vol. 148, Aug. 25, pp. 239–241). A description is given of two types of the "Ignitron" mercury-vapour arc rectifier produced by the British Thomson-Houston Co., Ltd., to enable precise control of the current of resistance-welding machines to be obtained. (*See* p. 275 A).

First Progress Report of the Joint Investigation of Continuous Welded Rail. H. F. Moore. (University of Illinois Engineering Experiment Station, 1939, Reprint No. 13). In 1937 arrangements were made by the Association of American Railroads and the Engineering Experiment Station of the University of Illinois for the investigation of welded joints in continuous welded rails. The types of welded joint to be studied include some made by oxy-acetylene welding, some made by the thermit process and some made by the electric resistance method. The laboratory investigation in progress includes: (1) Etch tests of the metal in specimens of welded rail joints. (2) Hardness surveys of the metal in the weld, in the transition zone and in the adjacent rail. (3) Examination of the structure under the microscope. (4) Chemical analyses of the steel of the weld, the transition zone and the rail. (5) Tensile, impact and fatigue tests of specimens cut from the three zones mentioned in (4). (6) Rolling-load fatigue tests of full-size specimens of welded rail joints. (7) Drop tests and bend tests of full-size welded rail joints.

The first part of the First Progress Report now presented is introductory in character and gives the constitution of the advisory committee, descriptions of the types of joint to be studied and a general outline of the work. The remainder of the report consists of the following papers:

Etch Tests, Metallographic Tests and Hardness Surveys, by R. E. Cramer and E. C. Bast.

Tests of Welded Joints under Repeated Wheel Load, by H. F. Moore, H. R. Thomas and N. J. Alleman.

Bend Tests and Drop Tests of Welded Joints. N. J. Alleman and H. F. Moore.

The report concludes with a bibliography of fifty-two references to the literature on welded rails.

The Welding of Boiler Drums and Shells. S. F. Dorey. (Transactions of the Liverpool Engineering Society, 1939, vol. 60, pp. 140–170). The author describes the forge-welding and the fusion-welding of boiler drums and shells, and discusses the materials used and the methods of inspection and testing employed in Great Britain, Germany and the United States.

Strip Welding. D. A. McArthur. (Steel, 1939, vol. 105, Aug. 28, pp. 42–44, 64). The author describes the technique employed for either the stitching or the welding together of the trailing end of one coil of steel strip and the leading end of the next coil at the entry end of a continuous pickling bath.

Strip Welding. S. M. Humphrey. (Steel, 1939, vol. 105, Aug. 21, pp. 48–49, 64). A description is given of a large resistance-welding machine for butt-welding the trailing edge of one coil of strip to the leading edge of the next coil. A large number of adjustments are available on this machine as it will weld strip from 12 to 38 in. in width and the two coils to be joined need not be of the same gauge.

The Welding of Non-Magnetic Steel in Switchgear Manufacture. (Engineering, 1939, vol. 139, July 28, p. 122). A description is given of the welding procedure adopted by the British Thomson-Houston Co., Ltd., for the welding of inserts of non-magnetic steel to mild steel in the construction of circuit-breaker top plates.

Brazing Galvanized Pipe. V. Forgett. (Steel, 1939, vol. 105, July 24, pp. 50–51). The author describes briefly a method of brazing joints in galvanised pipes without damaging the zinc coating. The success of the method depends upon the use of a special reducing flux. This flux is painted over the inside and outside of the pipe for 3 in. on each side of the joint.

Tests Using Methods of Determining the Capacity for Deformation of Multi-Run Welds in Dead Mild Steel. K. L. Zeyen. (Elektroschweisung, 1939, vol. 10, Feb., pp. 21–30; Apr., pp. 67–74; May, pp. 90–94). *See* p. 276 A.

Examinations and Tests for Fusion Welded Boiler Drums. L. W. Schuster. (Transactions of the Institute of Welding, 1939, vol. 2, July, pp. 151–159). The author describes the examinations and tests deemed necessary by the leading British insurance companies to ensure the production of satisfactory welded drums for steam-generating units and steam receivers, and explains the technical reasons for which the various rules were formulated.

MACHINING

(Continued from pp. 156 A–157 A)

Metallurgical Factors Affecting Machinability. H. W. Graham, J. D. Armour, P. Schane and M. N. Landis. (Metal Progress, 1939, vol. 36, July, pp. 53–56). This is a preliminary report of a committee appointed by the American Society for Metals to study the metallurgical factors affecting the machinability of steels. In the report these factors are dealt with under groups relating to manufacturing processes, composition of the steel, processing (*i.e.*, hot-working, cold-working and heat treatment), and to the physical characteristics. Tables are also presented showing the relative machinability of seventy S.A.E. (Society of Automotive Engineers) steels using steel S.A.E. 1112 with 100% machinability as a standard.

The Effect of Structure and Size of the Original Grain on the Machinability of Sections of Steels 40 and 50. Ya. Frid and L. Podboyskiy. (Stal, 1938, No. 10, pp. 53–58). (In Russian). The steels investigated contained carbon 0·36–0·54%, manganese 0·50–0·80%, silicon 0·17–0·37%, and phosphorus plus sulphur 0·08%. The effects of various structures obtained by heat treatment and of different grain size on the machinability were examined. The best machinability, as regards both ease of cutting and surface finish, was obtained in steels in which the eutectoid had a lamellar structure. The best heat treatment for good machinability consists of normalising at 880–900° C. for 30–40 min. prior to the final drawing, followed by slow cooling. In order to obtain a definite lamellar structure of the eutectoid it is necessary to start with coarse grained steel. The mechanical properties of steels with a structure of granular pearlite change more markedly on drawing (depending on the reduction) than those of steels with lamellar pearlite.

Free Machining Lead-Bearing Steels. (Metallurgia, 1939, vol. 20, July, pp. 95–98). The improvement in the machinability of steel by the addition of up to 0·25% of lead is discussed, and numerous tables and graphs are presented in which the physical properties of low-carbon, high-carbon and alloy steels with and without the addition of lead are compared.

PROPERTIES AND TESTS

(Continued from pp. 285 A–297 A)

Fifth Progress Report of the Joint Investigation of Fissures in Railroad Rails. H. F. Moore. (University of Illinois Engineering Experiment Station, 1939, Reprint No. 14). A research conducted by the Engineering Experiment Station of the University of Illinois, the Association of American Railroads and the Rail Manufacturers Technical Committee. In the introduction H. F. Moore outlines the work already carried out (*see* Journ. I. and S.I., 1938, No. II., p. 381 A for an abstract of the Fourth Progress Report) and gives lists of members of the various committees and the staff carrying out the tests. The remainder of this, the Fifth Progress Report is made up of the following papers :

Metallographic Tests, by R. E. Cramer and E. C. Bast.—The authors describe a method of treating ingots with hydrogen so that the rails produced from them are prone to develop a large number of shatter cracks. They then discuss a number of methods of controlled cooling, some of which were successful in preventing the formation of shatter cracks.

Bend Tests for Rails, by N. J. Alleman and H. F. Moore.—The authors describe a series of bend and drop tests undertaken to determine what effect the length of span adopted in the tests has upon the value of the results.

Effect of Heat Treatment on the Mechanical Properties of Heat-Treated Rail Steel, by S. W. Lyon.—The author gives an account of an investigation by means of heat treatment and hardness surveys of the ends of rails which had the object of determining the most suitable heat treatment to apply to produce the greatest resistance to batter.

Non-Destructive Tests, by J. L. Bisesi, R. S. Jensen and G. B. Bliss.—After describing some vibration and acoustic methods of testing rails in order to detect cracks, the authors report on an endeavour to relate the occurrence of defective rails, located by travelling electric-detector installations, to the weight and frequency of the loads passing over them.

Rolling-Load Tests for Batter of Rails, by H. R. Thomas and N. J. Alleman.—The authors discuss the results of rolling-load tests which have been completed since the Fourth Progress Report was published.

Proposed Service Tests of End-Hardened Rails, by H. R. Thomas.—The author outlines the programme of testing to be

undertaken by putting into service a number of rails end-hardened by different processes and carrying out hardness and other tests *in situ* from time to time.

Double-Impression Method of Determining the Brinell Hardness of Metals. (Machinery, 1939, vol. 54, Aug. 10, p. 596). A description is given of a simple method of making an approximate determination of the Brinell hardness of metals. It consists of placing a hardened steel ball between the material to be tested and a specimen of known hardness and pressing them in a simple arbor press or a vice. No measurement of the force exerted is required. The impressions on both materials are measured under a lens or microscope and the hardness can then be calculated within $\pm$ 3% by using the formula explained in the article.

Table of Approximate Comparison of Hardness Scales. (British Standards Institution, No. 860–1939). This British Standard contains tables enabling an approximate comparison of the diamond pyramid, Brinell and Rockwell hardness numbers to be made.

Hardness Testing. V. E. Lysaght. (Canadian Metals and Metallurgical Industries, 1939, vol. 2, June, pp. 131–135). The author, after explaining points which may lead to errors when using conversion tables for hardness numbers, discusses factors affecting the results obtained when testing very thin sheet; he refers in particular to side flow which causes lower readings, anvil effect which causes higher readings, and crushing or " punching through " which causes lower readings. In conclusion he describes the Knoop indenter developed by the National Bureau of Standards, which is suitable for testing very thin material and for making tests on small areas. This is a diamond tool in which the relationship between the long and short diagonals of the base of the pyramid is about 7 to 1 and that between the long diagonal of the base and the altitude of the pyramid approximately 30 to 1. For a given measurable dimension the depth of penetration with the Knoop indenter is less than one-fourth of that of the Vickers pyramid.

The Relationship between the Hardness and the Tensile Strength of Carbon Steel Wire. (Machinery, 1939, vol. 54, Sept. 14, pp. 741–742). Some tables are presented in which the data obtained from many thousands of observations of hardness tests on steel wires contained carbon from 0·25% to 1·00% are condensed and related to the tensile strength.

Hardness Problems in High Speed and High Alloy Tool Steels. K. Rosner. (Iron and Steel, 1939, vol. 12, July, pp. 616—620). The author describes two investigations concerning the hardness of tool steels. The first had the object of showing whether the hardness of a high-speed steel or high-alloy tool steel at an elevated temperature was a simple function of its hardness at room temperature. The results obtained show that the hardness of high-speed

and high-alloy tool steels at elevated temperatures depends not only on the hardness of these steels at room temperature, but also on their heat treatments. Tempering to secondary hardness results in higher hardness at elevated temperatures, as compared with the hardness values obtained by a heat treatment to primary hardness. The superiority of the specimens heat treated to secondary hardness is greatest at a temperature of 300° C. and diminishes with increasing temperature. The highest numerical value of this difference in hardness was shown by the cobalt high-speed steel. In the case of high-chromium high-carbon tool steel this difference was insignificant. He discusses briefly the advantages of a heat treatment of high-speed and high-alloy tool steels to secondary hardness. In the second investigation experiments were conducted to determine the conditions of heat treatment giving the best hardness at temperatures up to 500° C. for a tungsten-vanadium high-speed steel. A tempering method was found giving extraordinarily high hardness numbers at room temperature, nearly equalling the hardness of cobalt high-speed steel. This high hardness did not correspond to a higher hardness at temperatures above 200° C. of the same samples, as compared with samples heat-treated in the usual manner. Other experiments showed that too short or too long tempering both cause a distinct lowering of the hot-hardness, in spite of a satisfactory hardness at room temperature.

The Ageing of Super-Cooled Austenite in High-Speed Steel. I. I. Bornatskiy. (Metallurg, 1939, No. 3, pp. 56–64). (In Russian). The object of the investigation was to study the effect of the precipitation-hardening of supercooled austenite on the microstructure, position of the martensite point, hardness and the cutting properties of high-speed steel of the following composition: Carbon 0·75%, manganese 0·30%, silicon 0·30%, chromium 4·2%, tungsten 17·4%, vanadium 0·62%, sulphur 0·016%, phosphorus 0·019% and nickel 0·08%. The critical points Ac_1, Ac_2 and Ac_3 of the steel were between 820° and 870° C. As the quenching temperature was raised, the hardness of the steel fell off owing to an increase in the amount of residual austenite and a decrease in the amount of primary martensite. The quenching temperature for steel to be subjected to triple tempering at 560° C. should not be lower than 1250° C. The maximum quenching temperature should be some 20–30° C. below the temperature of formation of ledeburite. On heating, the transformation of α-iron to γ-iron occurs at 820–870° C. On air-cooling, the martensite point (upper temperature of Ar interval) is lower the higher the temperature to which the specimens had been heated and the longer the holding time. Experiments on the ageing of supercooled austenite (quenched from 1300° C.) on holding at temperatures of 600–700° C. were carried out. An increase in the latter temperature and the holding time intensifies the precipitation of carbides and results in a raising of the martensite point. At 700° C. the austenite grains become surrounded by a broad network

of troostite. The cutting tests showed that the ageing of supercooled austenite in molten lead at 580–600° C. for 40 min. increases the tool life by 20%, as compared with steel quenched in crude petroleum. Ageing at 650° C. for 3 hr. increases the tool life by 90% as compared with the petroleum-quenched tools. Ageing in each case was followed by air cooling.

The Strain Age Embrittlement of Steel. H. O'Neill. (Metallurgist, 1939, vol. 12, Aug., pp. 51–54). In this discussion of the increase in hardness and decrease in impact value which are imparted to steel by ageing at 250° C. after subjecting it to cold-work, the author gives the results of several experiments carried out on rolling-stock constructional material. In some tests the influence of cutting the specimens with the oxy-acetylene torch was investigated; the steel was first strained to 15% elongation on 5 in. and sawn longitudinally into two similar pieces; of these, one was allowed to strain-age naturally at room temperature, whilst a short piece was cut off the other with an oxy-acetylene torch. Hardness explorations of both pieces were then made over a period of fourteen days, and finally impact test specimens were made from both pieces. The results showed that strain-ageing had reduced the Izod value by at least 53%, whilst strain-ageing and flame-cutting had reduced it by 70%. The increase in hardness was greatest at about $1\frac{1}{8}$ in. from the burnt edge. The impact values of the two pieces had changed more than the hardness values. He also describes an experiment made to see whether welded structures which have to be flame-cut could be spared the accentuated brittleness produced by heating to 200° C. by flame-cutting while a stream of water flowed over the piece to cool it. It was found that the water-cooled specimen had twice the impact value of the other. He discusses next the fundamental causes of strain-age-hardening, and refers to a non-ageing steel called "Izett" brought out by Krupps in 1926. In the author's experience certain basic open-hearth steels and basic Bessemer steel are very liable to this defect. In conclusion he discusses various theories in explanation of strain-age-embrittlement, in particular that of C. A. Edwards, H. N. Jones and B. Walters (*see* Journ. I. and S.I., 1939, No. I., p. 341 P), but is himself of the opinion that the phenomenon is fundamentally due to some form of oxygen or nitrogen impurity in the steel.

The Strength of Metals at Elevated Temperatures. R. F. Miller. (Mechanical Engineering, 1939, vol. 61, Aug., pp. 589–594). The author describes some methods used in the research laboratories of the United States Steel Corporation for determining the rate of creep of specimens of steel at different temperatures and reproduces graphs showing the percentage elongation in relation to time. There are two recognised methods of relating stress to creep in the United States; one is to determine the stress which will produce a creep rate of 1% per 10,000 hr. and the other is to determine the stress which will produce a creep rate of 1% per 100,000 hr. The

latter is used when designing parts for steam turbines, in which the amount of creep must be exceedingly small.

Alternating-Current Bridge Thermostat for Creep Testing. L. E. Prosser. (Engineering, 1939, vol. 139, July 28, pp. 95–96). The author describes a new thermostat which has been developed for controlling the high-sensitivity creep-testing furnaces in the Engineering Department of the National Physical Laboratory. The thermostat has been designed to give a very sensitive control, and is at the same time robust, cheap and reliable. The principle of operation is that variation in the resistance of a platinum winding in the furnace will control the proportion of each minute during which a resistance in series with the furnace is short-circuited. By this means any deviation in temperature will change the effective heating of the furnace by a proportional amount.

Cast Iron in Engineering Construction. J. L. Francis. (Iron and Steel, 1939, vol. 12, Aug., pp. 684–688; Sept., pp. 725–730). Continuation of a series of articles. (*See* p. 222 A). In Part XII. the author deals mainly with the properties of the nickel-iron alloys, showing that additions of more than 10% of nickel render the structure austenitic. The main characteristics of the austenitic cast irons are: (1) A superior resistance to the effects of heat; (2) a marked degree of corrosion resistance; (3) with suitable compositions the iron is non-magnetic; (4) the electrical resistance is high whilst the temperature coefficient of resistance is low; and (5) the coefficient of expansion is high. He also considers in detail the properties of Nicrosilal and Nimol or Ni-Resist and the melting technique employed in producing these special alloys, and he concludes this part by discussing how nickel additions affect the heat treatment of cast iron. The author devotes Part XIII., which concludes the series, mainly to a discussion of the manufacture and properties of malleable iron; he also describes the effects produced by additions of copper, molybdenum, titanium, aluminium, nickel and chromium in malleable iron castings.

Application of Alloy Cast Irons to Crushing and Grinding Machines. L. Sanderson. (Metallurgia, 1939, vol. 20, July, p. 126). The author surveys briefly some special types of cast iron which are now produced for making parts of crushing and grinding machinery. In particular he mentions cast iron alloyed with nickel, nickel-chromium, nickel-chromium-molybdenum, copper-chromium-molybdenum and vanadium.

Trends in the Development of Alloy Steels. E. Houdremont. (Metallurgia, 1939, vol. 20, July, pp. 121–123). This is an abridged English translation of an article which appeared in Stahl und Eisen, 1939, vol. 59, Jan. 5, pp. 1–8; Jan. 12, pp. 33–39. (*See* Journ. I. and S.I., 1939, No. I., p. 238 A).

Low-Alloy Steels from Naturally Alloyed Pig Irons. S. Nekrytyy. (Stal, 1939, No. 2, pp. 17–22). (In Russian). After discussing the effects of phosphorus and copper additions on steel, which

increase the yield point without appreciably lowering the tensile strength or the ductility, while at the same time improving the corrosion resistance, the author passes on to deal with the mechanical properties and compositions of typical low-alloy steels, and concludes by examining the possibility of producing low-alloy steels from alloyed pig-iron obtained from the Khalilov and other Russian ores which contain titanium, vanadium, nickel, copper and cobalt. The compositions and properties of some low-alloy (manganese-chromium-nickel) steels produced from pig irons obtained from the Khalilov ores are given.

Use of Nickel in Excavating Machinery. H. Sano. (Japan Nickel Review, 1939, vol. 7, July, pp. 209–213). The author describes some applications of nickel steels for bucket pins, bushes and tumblers in dredging machinery and excavators.

Nickel Alloys in the Mining Industry. J. A. Rabbitt. (Japan Nickel Review, 1939, vol. 7, July, pp. 184–208). The author discusses the application of nickel alloys to mining machinery and equipment, giving numerous examples which demonstrate the additional safety, the reduction in weight, the increased wear resistance, the greater protection from corrosion and other advantages derived from the inclusion of nickel in the material.

Nickel in Ore Transportation Equipment and Accessories. K. Watanabe. (Japan Nickel Review, 1939, vol. 7, July, pp. 216–220). The author describes some of the benefits obtained by the use of nickel steel in mining cages, ore trucks, skips, locomotive parts, conveyor links and other machinery used for transporting ores.

Nickel Alloys in Air Compressors and Pumps for Use in Mines. S. Suzuki. (Japan Nickel Review, 1939, vol. 7, July, pp. 221–226). The author describes and illustrates parts of pumps and air compressors made of nickel alloys, all of which demonstrate the increased service which is obtained by their use.

Steels Used by the British Railways. T. H. Turner. (Metallurgia, 1939, vol. 20, July, pp. 103–104). The author gives a brief account of the applications of plain and alloy steels for the manufacture of rails, locomotive parts, signal wires, wheels, tyres, axles and other fittings for rolling stock.

Shipbuilding Steels. J. W. Donaldson. (Metallurgia, 1939, vol. 20, July, pp. 115–116). The author describes some of the special steels used in the construction of the " Queen Mary " and " Mauretania."

Steels in the Automobile and Aeronautical Industries. W. H. Hatfield. (Metallurgia, 1939, vol. 20, July, pp. 107–108, 124). The author discusses in general terms the application of carbon and special steels for the manufacture of parts for automobile and aeroplane engines. He presents two tables of the analyses, mechanical properties and heat treatment of these steels.

Strip Steel for Motor Car Wheel Rims. E. R. Mort. (Iron and Steel, 1939, vol. 12, Sept., pp. 712–714). The author points out the

physical properties, particularly the grain size and hardness, which are required in hot-rolled strip to render it suitable for rolling into rims for motor car wheels.

Steels for Power Plant. H. H. Burton. (Metallurgia, 1939, vol. 20, July, pp. 111–113, 124). The author discusses the properties of a number of special steels which have been developed for the manufacture of plant for generating electricity. These include steels for high-pressure boilers, superheater tubes, pipe-flange bolts, turbine rotors and turbine casings.

Modern Tool Steels. L. K. Everitt. (Metallurgia, 1939, vol. 20, July, pp. 114, 118 A). The author describes some recent developments in the manufacture of high-speed steels, die steels, steels for pneumatic tools and tungsten-carbide cutting alloys.

Steel Wire. A. T. Adam. (Metallurgia, 1939, vol. 20, July, pp. 117–118). The author discusses the properties of mild steel wire, alloy steel wire which is drawn for size and shape only, wire for ropes and springs, and wire for such special purposes as suspension bridges.

75th Anniversary of the Testing Station and 25th Anniversary of the Material Acceptance Office of Fried. Krupp A.-G. Essen. W. Hengemühle and K. Reichert. (Stahl und Eisen, 1939, vol. 59, July 13, pp. 819–820). The authors present a brief history of the growth of the steel-testing laboratories at the works of Friedrich Krupp A.-G., Essen.

The Standardisation of Grey Cast Iron in Foreign Countries. H. Jungbluth. (Giesserei, 1939, vol. 26, Aug. 25, pp. 433–437). The author first describes how the standards for grey cast iron have been defined in relation to other standards and materials in various countries. He then shows that on the basis of the wall-thickness susceptibility classification can be carried out—and has been done—either by " materials " or by " properties." Finally he demonstrates that, again on the basis of the wall-thickness susceptibility of the cast iron, the testing of the properties provided for in the standard can be related to the cast iron as such or to the cast piece; for both cases, prototypes are included in the various national standards.

British Standard Schedule of Sizes of Metal Containers for Food Products for British Packers in the United Kingdom. (British Standards Institution, No. 866–1939).

British Standard Specification for Steel Straightedges of Rectangular Section. (British Standards Institution, No. 863–1939).

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 298 A–302 A)

Faults in Photomicrography. J. V. Butterfield. (Heat Treating and Forging, 1939, vol. 25, July, pp. 335–338). The author draws attention to some fundamental principles which must be observed in order to obtain good photomicrographs. The most important points are the correct alignment of the illuminator, microscope and camera, and the proper adjustment of the iris diaphragm.

A New Focusing Device for Micrography. R. L. Dowdell and C. H. Green. (Metal Progress, 1939, vol. 36, July, pp. 40–41). The authors describe a device which facilitates the focusing of images in micrography. As the resolving power of an objective increases focusing becomes more sensitive and it is considered good practice to focus images on the glass slide with a magnifying glass. It is usual to hold the magnifier in mid-air, but to avoid the tediousness of this the device here described has been perfected. It consists of a frame in which is suspended a piece of plate glass ground on the side nearest the lens system and on which the magnifier is permanently fixed. With this device considerable time can be saved because it is always balanced so that it hangs in the proper plane, and it eliminates the necessity of putting in a ground glass slide to view the complete field to be photographed.

Genesis of Pearlite and Martensite. F. H. Allison, jun. (Metal Progress, 1939, vol. 36, July, pp. 60–64). The author explains and discusses the transformation of austenite in 0·78% carbon steel to pearlite and martensite at different rates of cooling from above the critical point (1340° F.) by reference to Bain and Davenport's **S** curves.

Isothermal Decomposition of Austenite in Die Steels. M. P. Braun and L. D. Khabinskaya. (Metallurg, 1939, No. 3, pp. 71–80). (In Russian). Four low-alloy steels of the chromium-nickel-molybdenum, chromium-tungsten-silicon and chromium-manganese-molybdenum type were studied. The decomposition of the austenite (**S** curves) was investigated by magnetometric and volumetric methods. The microstructures and mechanical properties after various heat treatments were determined. In conclusion the tendency to distortion (French's discs) and to cracking as a result of heat treatment was investigated. The chromium-manganese-molybdenum steel after suitable heat treatment (heating to 800° C., holding in a salt bath at 550° for 25 min., cooling in oil and finally tempering at 550°) was found to develop mechanical

properties which made it appear to be a suitable substitute for chromium-nickel-molybdenum die steel.

Melting, and some Properties of Hypo-Eutectoid Steels with Controlled Austenite Grain Size. Ya. Frid, G. Nazarov and L. Podviyskiy. (Stal, No. 12, 1938, pp. 61–62). (In Russian). Data obtained from a large number of both open-hearth and electric-furnace heats showed that the amount of aluminium required to produce a given fine grain depended on the degree of deoxidation of the steel before the addition of the aluminium. This and actual chemical analysis of the aluminium and Al_2O_3 contents in samples of different grain sizes tended in general to confirm McQuaid's theory that fine grain size is due to excess of aluminium. Carbon and silicon raise the temperature at which growth of the austenite grains occurs and thus reduce the amount of aluminium required to produce fine grain size. Manganese has the opposite effect. Aluminium was most effective when added in small pieces. Experiments on the hardenability showed that the effect of grain size on this property was greater than those of the manganese and carbon contents, though the latter were by no means negligible.

The Recrystallisation of the Stainless Steels of the 18/8 Type by Annealing after Cold Working. J. Vialle. (Revue de Métallurgie, Mémoires, 1939, vol. 36, June, pp. 288–296). After considering in general terms the heating of 18/8 chromium-nickel steel to 600–900° C. which causes precipitation of the carbides in the grain boundaries, the author made a detailed study of the recrystallisation of these steels by subjecting specimens to different forms of heat treatment and to cold-work and then examining the grain size and the structure. From the data obtained he plotted curves showing the effects of the amount of deformation and of the temperatures of the heat treatment on the grain size. In the case of specimens which had been elongated by 40% in the cold state the results showed that for a given time and temperature of heat treatment the size of the grains increased as the amount of elongation decreased. Another series of experiments confirmed the conclusion of Hanemann and Czochralski that the grain size prior to the cold-working did not affect the grain size after recrystallisation. Finally the author endeavoured to trace a relationship between the grain size and the composition of the steel but could not establish this; he did, however, confirm the refining influence of titanium, and his tests showed that 0·25% of this element produced a very fine grain size and imparted good heat-resisting properties to the steel.

CORROSION OF IRON AND STEEL

(Continued from pp. 303 A–306 A)

Seventh Corrosion Conference. Report on the 1938 Corrosion Congress held on Nov. 15, 1938, in Berlin. (Korrosion VII. Bericht über die Korrosionstagung 1938 am 15 November 1938 in Berlin. Berlin 1939 : V.D.I.-Verlag G.m.b.H.). The subject of the Seventh German Conference on Corrosion, held in Berlin on November 15, 1938, was suggested by the Deutscher Verein von Gas- und Wasserfachmännern and was the corrosion of regulators, meters and stopcocks (*Absperrorganen*). The account of the proceedings contains 18 short papers centred round this theme. It is not practicable to abstract each of them, in view of the mass of detail that they contain relating to a rather specialised subject, but, in general, it may be said that they provide interesting information concerning the corrosion of water meters (G. Eggers), electrical measuring instruments and controls (F. Lieneweg) and of valves, stopcocks and similar fittings in marine, boiler and other fields of service. The corrosion and construction of gas meters is discussed in three papers by K. Bunte, W. J. Müller and H. Rosenthal, whilst F. Stief contributes a paper on the preservation of gas supply systems by careful purification of the gas and E. Naumann a companion paper on the protection of water pipes by correct water treatment. Another feature of the conference as a whole is the emphasis laid on the importance of corrosion research in facilitating the introduction of substitute materials as part of the German four-year plan. This is discussed in detail as regards the rolling stock of the German State Railways by F. Wolf, who states, for instance, that the copper formerly used in making all locomotive steam, air and water pipes has now been replaced by steel, whilst aluminium alloys have been successfully substituted for brass in passenger carriages. It is to be hoped that, in the words of Professor E. H. Schulz, who summarised the proceedings, the developments and procedures introduced as a result of this national movement may prove to have a felicitous effect in fostering technical progress in the world as a whole.

The Corrosion of Metals. O. P. Watts. (Engineer, 1939, vol. 168, Aug. 11, pp. 166–168; Aug. 18, pp. 193–194; Aug. 25, pp. 221–222). The author states that the application of Faraday's law to corrosion may be expressed as follows : " The total of chemical change at the anode, where metals ordinarily enter the solution, equals that at the cathode, and at each electrode is proportional to the current, to the time, and to the chemical equivalents of the substances concerned." From this law the author derives four

types of corrosion, which are : (*a*) Corrosion by reduction in valence of some metal already in solution, without displacement of any cations from the electrolyte, *e.g.*, the corrosion of copper and iron in a solution of ferric chloride ; (*b*) corrosion by displacement of a metal, *e.g.*, the corrosion of iron by a solution of copper sulphate ; (*c*) corrosion by visible displacement of hydrogen, *e.g.*, the corrosion of commercial zinc or iron in dilute sulphuric acid ; and (*d*) corrosion by oxygen depolarisation, *e.g.*, copper in dilute sulphuric acid. He discusses these four types in detail and describes many experiments in which the use of inhibitors and other means of retarding the corrosion of ferrous and non-ferrous metals was examined.

The Causes of the Corrosion of Iron Storage Tanks by Fuel Oil and its Prevention. A. Fry, V. Duffek and C. Köck. (Korrosion und Metallschutz, 1939, vol. 15, July–Aug., pp. 217–224). The authors find that the corrosion of the plates of oil storage tanks is caused chiefly by the separating-out of the water contained in the oil ; this water lies on the bottom plates of the tank, and it will therefore be understood why these plates corrode much more than the vertical plates and those forming the top of the tank. The authors next investigated (*a*) means of determining the amount of water present in the oil, (*b*) the capacity of water to dissolve in, mix with or be dispersed in the oil, (*c*) the physical state of the water in the oil, and (*d*) the maximum quantity of water which the oil will dissolve. From the results obtained they suggest methods of removing the water from the oil and means for the removal of the moisture in the air which circulates through the tank ventilation pipes.

The Electrochemical Behaviour of the Stainless Chromium-, Chromium-Nickel-, and Chromium-Manganese Steels Compared with that of Pure Iron. E. Maurer. (Korrosion und Metallschutz, 1939, vol. 15, July–Aug., pp. 225–241). After briefly reviewing the history of the development of stainless steels and the methods of measuring differences in potential when such steels are immersed in electrolytes, the author shows that little information is available relating to the potential measurements of the non-magnetic chromium-nickel steels. He therefore carried out a systematic investigation of the potentials of ten different chromium-nickel steels, two high-manganese chromium steels, a specimen of electrolytic iron and a number of chromium steels using 1*N* iron sulphate solution and 1*N* sulphuric acid. The determinations were made under air and under nitrogen ; in the latter case potential measurements were made using some specimens in the as-tempered state and others the surface of which had been ground while immersed in the electrolyte. It was found that all specimens in the as-tempered state produced a higher potential than did those which had been ground. The high-manganese chromium steels and the straight chromium steels had practically the same potentials in 1*N* sulphuric acid as electrolytic iron. The potentials of the chromium-nickel steels in 1*N*

sulphuric acid fell into two groups, in one of which the potentials of ground specimens were only about half those of the straight chromium steels; the other group consisted of ground specimens the potentials of which were approximately the same as those of the straight chromium steels.

A Contribution to the Electrochemical Study of the Corrosion of Metals. V. Cupr. (Korrosion und Metallschutz, 1939, vol. 15, July–Aug., pp. 241–251). The author studied the electro-chemical properties of a number of chromium and nickel-chromium steels and compared these with the properties of passive chromium. He investigated the changes in potential of passive electrodes in 1*N* solutions of hydrochloric acid and perchloric acid. Of the four steels tested, that highest in nickel and chromium (38% and 21% respectively) showed the greatest resistance to attack. Using the theory of local cell formation the author found that a relationship existed between the potential of the steels examined and the acidity of the electrolytes, and he shows how to apply this relationship in order to predict the passivity of electrodes in a given medium.

Which is the Cathode of the Local Cell when Iron Rusts? S. Brennert. (Korrosion und Metallschutz, 1939, vol. 15, July–Aug., pp. 252–255). The author considers the three following theories relating to the rusting of iron in a neutral solution such as common salt dissolved in water: (1) The inclusions which have cathodic surfaces are the true cathodes, and their cathodic effect can only be increased by passing an ample supply of oxygen over the surface. (2) The surface of the pure metal acts as the cathode and the cathodic effect is increased by oxygen as in (1). (3) The surface over which the oxygen or air is passed is covered with a oxide layer which acts as the cathode. The author then describes an experiment of U. R. Evans in which a cell is constructed consisting of a slab of Armco iron and a slab of cast iron with a narrow space between them; the outside surfaces are sealed with wax and a celluloid cap is fitted over the top; the space between the slabs and the cap is filled up with 0·1*N* common salt solution; a trap to catch air and gas bubbles is arranged in the cap, and an aërated solution of 0·1*N* common salt is passed through the space between the slabs; the two slabs are connected to a sensitive galvanometer. This experiment showed that the Armco iron acted as the cathode and the cast iron as the anode, and the loss of weight of the latter was more than twice that of the former. The author carried out further experiments by passing hydrochloric acid and common salt solution between Armco iron and cast iron and between Armco iron and open-hearth steel. He found that in hydrochloric acid the Armco iron was anodic and in salt solution it was cathodic, and in explanation of this he suggests that in acid there are small cathodic surfaces formed by impurities such as graphite, and in the neutral solution the cathodic surfaces are much larger; these probably consist of iron oxide or iron hydrate layers on the Armco iron.

Electrochemical Studies of the Corrosion of Steel and Magnesium in Partly Inhibited Solutions. L. J. Benson, R. H. Brown and R. B. Mears. (Electrochemical Society, Sept. 1939, Preprint No. 22). The authors describe their investigation of the corrosion of steel in a solution of potassium chloride containing some potassium carbonate as an inhibitor. They found that the progress of the corrosion was mainly dependent upon the rate of the reaction at the anode, a condition which they call "being under anodic control." They also examined the corrosion of magnesium in a solution of common salt.

An Electrochemical Study of the Corrosion of Painted Iron. H. E. Haring and R. B. Gibney. (Electrochemical Society, Sept. 1939, Reprint No. 24). The authors refer to previous investigations of the relative protection characteristics of paints (*see* Journ. I and S.I., 1936, No. II., p. 84 A) and now describe their investigation of fifty different paints when used as primers. In these tests they obtained time-potential curves in 24-hr. tests and the results compared favourably with those obtained in one-year out-door exposure tests.

The Rate of Dissolution of Iron in Acids. M. B. Abramson and C. V. King. (Journal of the American Chemical Society, 1939, vol. 61, Sept., pp. 2290–2295). The rate of dissolution of very pure iron has been measured in solutions of several acids with potassium nitrate, hydrogen peroxide, potassium nitrite and *p*-nitrophenol as depolarisers. Of these, only the potassium nitrate was found to be reasonably satisfactory as a depolariser. The rate was studied in relation to the concentration of the depolariser, the acid concentration, the concentration of various added salts, the stirring speed and the temperature. The rate was also measured in ferric chloride solutions of various concentrations, at various stirring speeds and temperatures, with and without additions of acid. It was found that the rate of dissolution in ferric chloride is controlled by the diffusion under all conditions. In hydrochloric acid with sufficient chloride present it is also diffusion-controlled at low stirring speeds. Under other conditions (*e.g.*, higher stirring speeds, higher salt concentrations and low nitrate concentrations) it is in whole or in part controlled by a slower reaction, perhaps of a chemical nature, at the metal surface. Under conditions where the rate of dissolution is diffusion-controlled, the temperature coefficient is about 1·35 per 10° C.; when it is chemically controlled, the temperature coefficient is 2·0–2·4 per 10° C. The activation energies vary accordingly.

How to Overcome Corrosion in the Container. A. D. Ingham. (Sheet Metal Industries, 1939, vol. 13, Aug., pp. 1001, 1004). The author describes the causes of the corrosion of the inner surface of food cans and recommends a double coating of lacquer for cans which are to be used for black currants, raspberries and loganberries. He also describes a simple titration method of determining the thickness of the coating of tin on tinplate.

Metallic Coatings—Their Atmospheric Corrosion Resistance and Protective Value. S. G. Clarke. (Metal Industry, 1939, vol. 55, July 28, pp. 87–90; Aug. 11, pp. 133–136; Aug. 25, pp. 181–184). The author reviews the results of long-time outdoor and indoor corrosion tests in industrial and rural atmospheres on different metallic coatings on steel. For outdoor exposure the chief requirement, irrespective of the coating metal or the process of application, is the thickest coating practicable. This is needed for the following reasons: (*a*) Because the coating corrodes away; (*b*) to ensure absence of porosity as far as possible; (*c*) to assist the coating. The coating metals which show the highest corrosion resistance are generally those cathodic to steel under atmospheric conditions. Except for the decorative point of view, there is no evidence that corrosion of steel at small pores in a good thick adherent coating is harmful under ordinary conditions of use; nevertheless full advantage can only be taken of the high corrosion resistance of cathodic coatings in general when the coating is not damaged mechanically so as to expose appreciable areas of basis metal. With this restriction, lead and aluminium merit consideration for outdoor use. For industrial atmospheric exposure, nickel is of less value owing to its higher rate of corrosion, and copper would appear to be preferable, but the opposite may hold for non-industrial exposure. The undercoating for thin decorative chromium coatings requires to be of very low porosity to avoid staining by corrosion products from the basis metal; nickel corrodes through pores in the chromium, giving a dull film necessitating periodic cleaning. Great advantages would be offered by thick non-porous chromium coats. Zinc, although tending to have a lower corrosion resistance than the above-mentioned metals, gives a good serviceable coating for outdoor use. Cadmium is appreciably inferior in urban conditions. So far as has been determined, the lives of coatings applied by electrodeposition and hot-dipping are the same for equal thicknesses, but uneven distribution is a factor which tends to tell against electrodeposition. Life-comparisons do not appear to have been carried out with sprayed coatings, but in view of the substantial thickness which can be applied by spraying, a long life may be expected when the coating is satisfactorily applied. For indoor use under normal conditions, thinner coatings may be acceptable but continuity is important. The excellent appearance which can be obtained with electrodeposited coatings, of chromium for example, is advantageous. Zinc coatings normally offer good corrosion resistance and are somewhat superior to cadmium; on the other hand, in humid conditions in closed spaces where much condensation occurs, zinc is susceptible to rapid attack and is much inferior to cadmium.

Observations on the Behaviour of Steel Corroding under Cathodic Control in Soils. I. A. Denison and R. B. Darnielle. (Electrochemical Society, Sept., 1939, Preprint No. 21). The authors describe an investigation of the behaviour of steel corroding naturally in soils

in which the corrosion is controlled by the rate of the reaction at the cathode. They used a specially designed cell and found that the corrosion of steel in such cases is accompanied by a slight change in the potential at the anode with changes in the applied current and with time. The more positive open-circuit potentials assumed by the cathode with time indicate that the potential of the cathode tends to approach the potential of the oxygen electrode for the particular environment. They also found that approximately linear relationships existed between the loss of weight of the anode of the corrosion cell, the maximum short-circuit current developed by the cell and the current at the corrosion potential, and this suggests a possible electrical method for measuring the corrosiveness of soils. During the experiments it was found that a dense membrane of iron oxide was formed between the anode and the cathode the position of which varied; the membrane at some distance from the anode was characteristic of corrosive soils, and in mildly corrosive soils the membrane was formed in olose contact with the anode.

Some Observations Concerning Metal Cracking in Naval Boilers. W. C. Stewart. (Journal of the American Society of Naval Engineers, 1939, vol. 51, Aug., pp. 348–364). The author discusses caustic embrittlement and corrosion-fatigue in boiler plates in the light of his long experience at the Engineering Experimental Station of the United States Navy. Only one case of intercrystalline cracking has come to the attention of this Station in the last ten years. In considering the causes of boiler failures the author stresses the importance of correct design to eliminate as far as possible the development of stress concentrations. He describes and illustrates some examples of corrosion-fatigue cracks due to stress concentrations at the knuckles of head flanges and at the feed-water inlet pads. The corrosion of boilers can be reduced by keeping the oxygen content of the water as low as possible.

Thermoflux Non-Destructive Wall-Thickness Measurement. A. V. de Forest. (Iron Age, 1939, vol. 144, July 13, pp. 82–85: Iron and Coal Trades Review, 1939, vol. 139, Aug. 11, pp. 193–194). A description is given of a thermo-electric device for measuring the thickness of the shell plate of boilers and pressure vessels for corrosion-testing purposes. This method replaces that of drilling holes through the shell and subsequently plugging them, which creates an undesirable source of weakness. It is known as the "Thermoflux" method. The measurement is made by applying heat at a controlled rate for a limited time, and measuring the resulting rise in temperature. For steel boiler plate, the heat is most conveniently generated in the metal itself by an alternating-current magnetic yoke held in contact with the surface. A thermocouple is applied between the legs of the yoke, and the rise in temperature after a definite length of time is used as the thickness indication.

ANALYSIS

(Continued from pp. 239 A–243 A)

The Determination of Copper by Precipitation with Salicylaldoxime. E. Stengel. (Technische Mitteilungen Krupp, Forschungsberichte, 1939, vol. 2, July, pp. 87–92). Reif's method for the determination of copper in steel (*see* Journ. I. and S.I., 1932, No. II., p. 662), using salicylaldoxime as a reagent, has been slightly varied, and adapted to the determination of copper in alloy steels. A special method has been developed for alloy steels containing tungsten.

Photo-Electric Method of Determining Molybdenum in Steel. A. L. Davydov and V. F. Mal'tsev. (Zavodskaya Laboratoriya, 1939, No. 3, pp. 264–268). (In Russian). A detailed study was made of the factors affecting the reaction of molybdenum with potassium thiocyanate, using a selenium cell colorimeter. It was found that the reaction is best carried out in 2–3N(H_2SO_4 + HNO_3) solution, the iron being reduced with the minimum amount of stannous chloride. Under these conditions of acidity the coloration is independent of temperature and is unaffected by excess of potassium cyanate. Up to 2% of chromium and up to 1% of nickel do not influence the absorption coefficient. A calibration curve is used to read off the results. The maximum error in a number of determinations was 4% of the amount being determined. The time taken is 40–45 min.

Colorimetric Determination of Nickel as Nickel-Ammonia Complex Ion. G. H. Ayres and F. Smith. (Industrial and Engineering Chemistry, Analytical Edition, 1939, vol. 11, July 15, pp. 365–367). A method has been developed for the colorimetric estimation of nickel as its ammonia complex. As little as 5 mg. of nickel can be detected with certainty. The method has been applied to the determination of nickel in steel after previous separation with dimethylglyoxime.

Determination of Nitrogen in Stainless Steels. T. R. Cunningham and H. L. Hamner. (Industrial and Engineering Chemistry, Analytical Edition, 1939, vol. 11, June 15, pp. 303–304). Jordan and Swindell's method (*see* Journ. I and S.I., 1923, No. I., p. 744) is adapted to the determination of nitrogen in steels containing alloy additions which form insoluble nitrides. The results are in very good agreement with values obtained by the vacuum fusion method.

Solubility and Diffusion of Oxygen in Solid Iron. A. B. Wilder. (Heat Treating and Forging, 1939, vol. 25, June, pp. 273–277). The author describes an apparatus and procedure for determining the oxygen in iron which is a modified form of C. H. Herty's method.

Using samples of specially prepared almost pure iron he determined the solubility of oxygen in it at temperatures up to 1300° C. The solubility of oxygen in ferrite increased with increasing temperature and reached a maximum at 0·07%. The solubility of oxygen in γ-iron at 975° C. was 0·08%, at 1075° C. 0·025%, and at 1300° C. 0·35%. These data indicate that the solubility of oxygen in steel decreases after 980° C. is reached. The amount of diffusible oxygen in ingot iron determined by the Ledebur method at 500° C. was as great as that obtained at 1100° C. The time required to remove the oxygen was, however, longer and no blank correction for the apparatus was required. Oxygen was also evolved at 300° C. and the maximum amount of diffusible oxygen was obtained at 800° or 1100° C. in a period of 1 hr. At 800° and 1100° C. a blank correction for the apparatus was required as silica gives off oxygen in the presence of iron at these temperatures.

Rapid Colorimetric Method of Determining Phosphorus in Ferrous Metals in the Presence of Arsenic. V. D. Konkin. (Zavodskaya Laboratoriya, 1939, No. 3, pp. 322–324). (In Russian). The steel is dissolved in nitric acid and the solution is boiled. It is then oxidised with potassium permanganate solution, the MnO_2 precipitate being destroyed by the addition of 10% of sodium nitrite, the nitrous fumes being removed by boiling. After cooling, the solution is treated with ammonium vanadate and ammonium molybdate, which gives a coloured soluble compound—$(NH_4)_3PO_4.VO_3.16MoO_3$—with the phosphate. The latter is estimated colorimetrically against a solution prepared from a steel (free from chromium and nickel) of known phosphorus content. The time required is 10–12 min.

A Note on the Determination of Phosphorus in Vanadium Slags. E. Stengel. (Technische Mitteilungen Krupp, Forschungsberichte, 1939, vol. 2, July, pp. 95–97). The author examines the more recent methods recommended for the determination of phosphorus in the presence of vanadium with regard to their applicability to the analysis of converter slags rich in vanadium. He suggests a modified method, the main feature of which is the application of only a very slight excess of the reducing agent (ferrous sulphate) when precipitating phosphorus with ammonium molybdate in the presence of vanadium.

Some Experiments in Connection with the Polarographic Determination of Vanadium and Chromium and with the Polarometric Titration of Molybdenum in Steels. G. Thanheiser and J. Willems. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, Aug., pp. 73–83). The authors tried to determine vanadium, chromium and molybdenum after separation from iron by alkali hydroxide. The results obtained for vanadium were not reliable owing to the presence of small amounts of iron which could not easily be eliminated from the alkaline solution. In the presence of chromium the determination of vanadium offered still greater difficulties, and the experiments for

the polarographic determination of vanadium in steel were therefore discontinued. A method for the polarographic determination of chromium was tested, and the influence of the temperature, of the rate of the drops from the capillary tube and of the hydroxyl-ion concentration on the results was determined. Molybdenum, tungsten, vanadium and aluminium did not interfere. Reliable results were obtained also after the introduction of a compensation method for the determination of the diffusion current, so that the rapidity of the method became greater owing to the elimination of the photographic determination of the current-voltage curve. As the polarographic method proved not to be applicable for the determination of molybdenum, a polarometric method based on the titration of molybdate with lead perchlorate was developed. An excess of lead is indicated by a diffusion current. The method has been adapted to the determination of molybdenum in tungsten-bearing and tungsten-free steels. The advantages of this polarometric method, possibly also for the determination of other metals, are pointed out.

A "Visual" Determination of Vanadium in Iron Ores, Slags and Similar Materials. E. Stengel. (Technische Mitteilungen Krupp, Forschungsberichte, 1939, vol. 2, July, pp. 93–94). The method of isolating vanadium as sulphovanadate has been adapted for the determination of this metal in iron ores, slags, &c.

The Examination of Vanadium-Bearing Slag. E. Piper. (Stahl und Eisen, 1939, vol. 59, July 27, pp. 862–863). The author describes a rapid method for the determination of vanadium in vanadium-bearing slags.

Identification of Inclusions in Steel by the Use of Reflected Polarized Light. M. A. Scheil, M. Baeyertz and J. R. Vilella. (Transactions of the American Society for Metals, 1939, vol. 27, June, pp. 479–501). The authors explain the principles of the use of polarised light for the examination of metals and describe the components of the apparatus used. They then discuss the application of this technique for the discovery and identification of non-metallic inclusions in steel, pointing out some of the advantages of this method of investigation. These advantages include the fact that fully transparent inclusions can be detected, the isotropic behaviour can be studied and the colour of the transmitted light determined. In conclusion the authors present comprehensive lists under the following headings: (*a*) Included minerals which always remain dark during rotation through 360°. (*b*) Translucent isotropic mineral inclusions. (*c*) Opaque minerals showing anisotropic behaviour. (*d*) Translucent anisotropic minerals with weak birefringence. (*e*) Translucent anisotropic minerals with strong birefringence. There is a bibliography with fifty-two references to the literature on the use of polarised light for mineral and metallurgical examinations.

Sampling of Ferro-Alloys for Analysis. M. V. Babaev. (Zavodskaya Laboratoriya, 1939, No. 3, pp. 317–320). (In Russian).

Such peculiarities as segregation, heterogeneity, special inclusions &c., and the special precautions which have to be taken in sampling ferro-silicon, high-carbon ferro-chromium, low-carbon ferro-chromium, ferro-tungsten and ferro-molybdenum are described.

Routine Spectroscopic Analysis in Ford Motor Co. Foundry. H. B. Vincent and R. A. Sawyer. (Metal Progress, 1939, vol. 36, July, pp. 35–39). The authors present an illustrated description of the spectrographic laboratory recently opened by the Ford Motor Co. for making rapid analyses as a means of controlling the metal produced by their cupolas. The laboratory equipment includes a transposing apparatus consisting of a slide rule and chart which enables the readings taken on the light-density comparator to be converted into percentages. In this laboratory the determinations of five elements in a sample can be completed and returned to the foundry in six minutes.

The Rational Analysis of Coals. I. The Determination of Fusain Content. R. Belcher and A. L. Godbert. (Fuel in Science and Practice, 1939, vol. 18, Sept., pp. 270–274). The authors describe their tests on two methods of determining the fusain content of a coal. The amount of fusain is important because it has a marked effect on the coking properties of coal. Both methods are chemical and involve the oxidation of the coal, but they are based on different principles. In the Heathcoat method the coal is oxidised under such conditions that the non-fusain material becomes soluble in alkali whilst the fusain remains substantially unattacked. In the other method advantage is taken of the fact that the oxidation of the non-fusain material by concentrated nitric acid appears to be dependent on the concentration of the reactants, whilst the oxidation of the fusain appears to be independent of the concentration of the reactants.

Methods of Analyzing Coal and Coke. F. M. Stanton, A. C. Fieldner and W. A. Selvig. (United States Bureau of Mines, 1938, Technical Paper No. 8). The first edition of the paper describing the methods of sampling and analysing coal and coke employed by the United States Bureau of Mines was published in 1912 and revised editions were published in 1913, 1926 and 1929. In the present revised edition the authors include some changes in analytical procedure which have been introduced since 1929, methods for the determination of the forms of sulphur in coal, of the forms of iron in coal-ash slags and clinkers, the agglomerating index of coal, and methods of analysing coal and coke ashes.

The Development of a Rapid Technique for the Determination by Combustion of Carbon and Hydrogen in Organic Substances with Special Reference to the Ultimate Analysis of Coal. D. Millin. (Journal of the Society of Chemical Industry, 1939, vol. 58, June, pp. 215–220). The author describes a rapid macro-method for the determination of carbon and hydrogen in organic substances, using only standard equipment and reagents. The results are

obtained within 20 to 25 min. The combustion is carried out in a rapid current of oxygen (or air when this is desirable) at a velocity up to 250 ml. per min. No modification from standard practice in the charge of the combustion tube is necessary to promote complete combustion and prevent interference by sulphur and nitrogen at this high velocity. The quantitative absorption of water and carbon dioxide is effected by the use of suitable reagents and absorption tubes.

The Determination of Hydrogen in Gases. R. Belcher and C. E. Spooner. (Fuel in Science and Practice, 1939, vol. 18, June, pp. 164–170). The authors examine the methods of determining the hydrogen present in gases evolved during the distillation of coal and find that the most satisfactory absorbent to use in the Bone-Wheeler apparatus is colloidal palladium/sodium-picrate solution. They also describe a new method using silver oxide heated to 100° C., in which the absorption of hydrogen is rapid and methane and ethane are unattacked.

A New Method for the Determination of Volatile Matter in Solid Fuels. T. J. Kalinski and W. Dmowska. (Fuel in Science and Practice, 1939, vol. 18, Sept., pp. 275–277). The authors describe the Dolinsky method of determining the volatile matter in coal. In this method a silica crucible in a small muffle furnace is used instead of the directly-heated platinum crucible used in some American methods and it is claimed that as the rate of heating is slower the new method is more suitable for low-rank coals high in volatile matter.

BOOK NOTICE

(Continued from pp. 307 A–309 A)

"*Vom Ursprung und Werden der Buderus'schen Eisenwerke Wetzlar.*" La. 8vo. Band I. pp. xv + 375; Band II. pp. vii + 365. Illustrated. Munich, 1938: Verlag F. Bruckmann. K.G.

This magnificent work, a fine specimen of printing and illustration, deals with the history, extending over 200 years, of the firm of Buderus. Its interest is, however, wider than might be expected from its nominal restrictions to the record of a single firm. The three authors deal with separate sections of the subject, Dr. H. Schubert writing on the history of the iron trade in the district down to the end of the 18th century, Dr. Ing. J. Ferfer with the later history of the firm of Buderus, and Dr. G. Schache with the amalgamation with the Hesse-Nassau Hüttenverein.

The first section is of special interest to all students of the history of iron and steel. Dr. Schubert, a trained historian, has already published a "Geschichte der nassauischen Eisenindustrie" (Marburg, 1937), a work undertaken at the request of Dr. Ludwig Beck. This, one of the most completely documented works on any regional industry, covers the history from the earliest times to the Thirty Years War. The present work does not go back as far as prehistoric times, but it deals in a most interesting way with the economic conditions in the iron industry of this part of Germany in the Middle Ages and the period of the Renaissance. It is interesting to note that the art of making steel from iron was, in the early part of the 17th century, kept strictly secret, and many persons came to grief in attempting to set up an industry of the kind. The origins of the cementation process are dealt with in detail. It may come as a surprise to many readers that a certain F. N. Alberti, engaged in 1706 to equip an ironworks, made it a condition of his appointment that he should be provided with a chemical laboratory! He was of an inventive turn, but there is no record of his having advanced the chemistry of ironmaking.

The firm of Buderus (latinised from Buder) was founded in 1731. Its development is described in great detail, and the records of successive reconstructions of works and the introduction of new processes are very valuable. It is fortunate that they have been so well preserved and the work will be found a mine of information for future historians.

C. H. DESCH.

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